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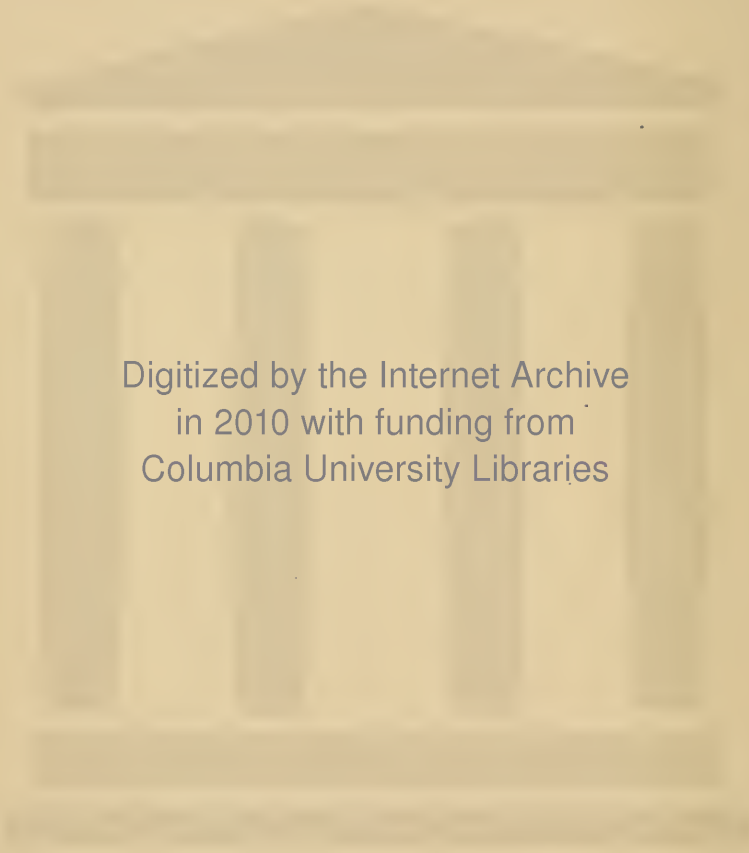
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A MANUAL

OF

NORMAL HISTOLOGY

AND

ORGANOGRAPHY

BY

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Fourth Edition, Thoroughly Revised

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PREFACE TO FOURTH EDITION.

THE cordial reception given this text is much appreciated by both the author and the publishers. In issuing a fourth edition the chapters have again been carefully reviewed and the known facts to date in elementary histology have been properly recorded.

The new introduction is written wholly for the elementary student, to arouse in him an interest in the subject matter of the text, and to show the close relation of normal histology to kindred important sciences. The text on spermatogenesis has been enlarged and the known facts stated in as clear and brief a manner as possible. Some of the figures have been replaced with new ones, and minor changes have been introduced throughout the text wherever the subject matter could be improved.

In this, as well as in former editions, the author has kept in mind his original fundamental purpose, to issue a clear and concise text that could be used as a basis on which the instructor might "build and complete his ideal elementary course in histology."

CHARLES HILL.

CHICAGO, ILL.,
September, 1917.

PREFACE.

This manual is written in the interest of elementary students. The fundamental facts in histology have therefore been presented in as clear and concise a manner as possible, and theories advanced only to simplify the facts and aid the memory in their retention. The figures have been selected with considerable care and are intended to illustrate the salient points of the text. They are to be studied as critically as the text, and to further facilitate such a study the descriptive terms are placed on the figures rather than in foot-notes.

The oral cavity deserves more attention than is usually given this subject. Neglect of proper care of teeth is a common failing, and the cause may be traced directly to a lack of knowledge of their structure and function. This chapter has therefore been enlarged. The author is greatly indebted to Professor Frederick B. Noyes, of the Northwestern University Dental School, for contributing most excellent figures on this subject. His critical essays form the basis for the descriptive part of this chapter.

The author believes most thoroughly in the laboratory method of study. He believes, too, that the laboratory work should precede the class-

room work, for which this manual is written. Laboratory technique, however, is so extensive a subject that a laboratory text, or the teacher's personal outlines, should be used for this particular work. In conformity with this view, only the fundamental principles of laboratory technique are outlined in the text.

Lastly, the subjects treated have been made fundamental and brief, that the teacher in charge may supplement the chapters by collateral work as may fit the particular course offered. It is therefore a basis on which the instructor may build and complete his ideal elementary course in histology.

CHARLES HILL.

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A MANUAL OF
NORMAL HISTOLOGY
AND
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INTRODUCTION.

PROTOPLASM.

In all this material world, with its complexity of products, there are but two forms of material things—namely, living matter or *protoplasm* and lifeless or dead matter. Protoplasm is not life. We do not know what life is, but whatever it is, we know it is not a material substance. We cannot see, feel, taste, touch, or weigh life, but we can do all these things with protoplasm. Spencer defines life as the "continuous adjustment of internal relations to external relations"—an acceptable concept.

Protoplasm always reflects life, and it is therefore regarded as the physical basis of life. Protoplasm, whether in plant or in animal, shows a uniformly related structure and has many identical characteristics. It is a colorless, transparent, jelly-like substance, of an albuminoid nature, resembling the

white of an egg. It differs from all lifeless matter in being able to *reproduce* itself, *repair* a wasted or depleted condition, *develop*, and *grow*. The sharpest kind of a line divides this living matter from dead matter, and yet we know that the closest relations and interrelations do exist. Even in our own physical bodies these two forms prevail, for the outer layer of the skin, the hair and nails, the liquid part of blood and lymph, the fibers of ligaments and tendons, the lime of bone, all are lifeless or dead matter. While today we firmly believe that living matter develops only from pre-existing living matter, we know that dead matter is constantly and unceasingly being incorporated into living matter, actually transformed into living matter through the mysterious elaboration of this selfsame living substance. Thousands of tons of dead matter are thus daily converted into living matter, throughout the animal and vegetable kingdoms, on land and in the seas. Were this constructive force nature's only process, a most unfortunate condition would soon prevail, with a dearth of the one form and a great surplus of the other—the living. But we recognize a reverse current equally strong whereby the "dust shall return to the earth as it was and the spirit to the God who gave it." That mysterious and insidious enemy Death is absolutely necessary that man, or any other living being, may live. It is the duty of the medical profession to divert this return current as far as possible that humanity, one and all, may enjoy threescore and ten happy years.

Protoplasm, so intimately associated with life, has

been subjected to all forms of analyses. The chemist tells us that protoplasm, whether animal or plant, yields the following elements: *carbon*, *hydrogen*, *oxygen*, *nitrogen*, and some *sulphur*. He is unable to tell us the combining relation of these elements in protoplasm, for the obvious reason that in his analyses protoplasm as living substance is destroyed and life has departed. But it is of interest to know that these elements, combined in some mysterious and unknown way, make this marvelous substance living matter. It is also of interest to reflect briefly upon the individual peculiarities of these elements. *Carbon* is a solid, exists free in nature, and remarkable for its allotropic forms, it being found as coal, or graphite, or diamond. Its combining power with other elements is extensive, and its durability is well known. *Hydrogen* is a gas. It is the lightest known substance. It is practically never found free in nature. Its combinations with other elements are many, forming often very stable compounds, the most common being its union with oxygen to form water. *Oxygen* is a gas and found free in nature, forming nearly 20 per cent. of the atmosphere. Its combining power is perhaps the most extensive of all the elements, forming many stable oxides. *Nitrogen* is also a gas and found free in nature, forming about 79 per cent. of the atmosphere. Unlike oxygen, its combining power with other elements is very weak, and when it does so combine the substances formed are very unstable. Nitrogen, therefore, is one of the chief elements in our explosives. *Sulphur*, like carbon, is remarkable for

its allotropic forms. Very small amounts of sulphur are found in living matter.

Protoplasm is a restless substance, its granules manifesting a slow ameboid movement, which becomes accelerated with increased physiological activity. At the end of a day's labor and toil it is not only exhausted but actually depleted, requiring repair and the replacing of its lost particles, which is accomplished by some marvelous, subtle, intrinsic power so characteristic of living matter. Food is the raw material utilized for this purpose, and it naturally follows that the essential elements of food, whether for plants or animals, must be identical with those found in protoplasm—namely, carbon, hydrogen, oxygen, nitrogen, and some sulphur. This is universally the case, as we find these present in the necessary food products, such as carbohydrates, hydrocarbons, albuminoids, and proteins. As a matter of fact, the diet of man is largely the protoplasm of some other living organism, animal or vegetable, or both. Huxley, in his lecture on the "Physical Basis of Life," very fittingly outlines this transmutation of the elements of protoplasm when he says that in order to replace the "number of grains of protoplasm and other bodily substances wasted in maintaining my vital processes . . . I shall probably have recourse to the substance commonly called mutton . . . and the subtle influence to which it will then be subjected will convert the dead protoplasm into living protoplasm and transubstantiate sheep into man. Nor is this all. If digestion were a thing to be trifled with, I might sup upon lobster

and the matter of life of the crustacea would undergo the same wonderful metamorphosis into humanity. And were I to return to my own place by sea and undergo shipwreck the crustacea might and probably would return the compliment and demonstrate our common nature by turning my protoplasm into living lobster."

The medical student is here reminded of the constant warfare being waged between many forms of living matter. We acknowledge today that most of the diseases to which mankind is an heir and a victim are nothing else than vicious attacks upon us by some form of living matter. Tuberculosis, pneumonia, diphtheria, typhoid, tetanus, cholera, bubonic plague, and many other serious and fatal diseases are now directly traced to invasions of micro-organisms, truly living things. Self-preservation is nature's first law and it is God's law. Protective selfishness and the preservation of a race, whatever be the sacrifice, is a fundamental principle deeply implanted in every form of living organism. There is, therefore, no mercy shown in this warfare. There is no hope of peace in this conflict, nay, not even a respite, and sooner or later practically each one of us must fall a victim to the enemy's invasion.

The discovery of the germ origin of disease has placed the study of medicine on a new and substantial scientific basis. Not satisfied with merely a defensive program, this warfare, by means of preventive medicine, has assumed the offensive to such a degree that the disease scourges which in the past sometimes decimated a people are today an impossibility.

Histology is the science that treats of cells and their products, therefore it is largely a study of protoplasm. The fundamental principles of therapeutics are based upon the action of drugs on protoplasm, Pathology involves a recognition of microscopic changes, other than normal, in living matter. Physiology has much to say about the actions and products of this same substance. Embryology traces the developmental history of protoplasm to form tissues, organs, and a new living being. It is this great importance of protoplasm, and particularly its relation to histology, that has prompted these introductory remarks.

CHAPTER I.

DEVELOPMENT.

The human body is composed of related structural units that may be grouped in a series of gradually increasing complexity. The simplest structural unit is the *cell*, which is defined as a spacially limited mass of protoplasm capable under certain conditions of assimilation, growth, and reproduction. It is a microscopic unit and forms the physical basis of life. The next grade of units is a *tissue*, which consists of a complex of similarly differentiated cells and their derivatives. Embryonic tissues are mostly cellular, while in some tissues of the adult body, such as bone and cartilage, the cell products predominate. The next higher grade of units is an *organ*, which structurally consists of a complex of tissues forming a body with a definite internal structure and external form. Lastly, the highest structural unit is a *system*, such as the nervous system, digestive system, respiratory system, a series of which, collectively, make up the human body.

Histology is the branch of science that treats of cells and their derivatives. These cells, in the adult, are modified according to their intrinsic qualities, environment, function, and varied experiences, which enable us to classify them and ultimately place them in a few elementary groups.

The *ovum*, or starting-point of every individual, is a cell. *Human embryology* comprises its intra-

uterine development. *Ontogeny* is a broader term, which includes not only embryology, but the developmental history of an individual up to old age or the senile condition. There is another form of development, much slower, but just as certain as ontogeny. This affects not only the individual, but, collectively, every member of the animal group. In the study of races there is ample evidence that structural changes

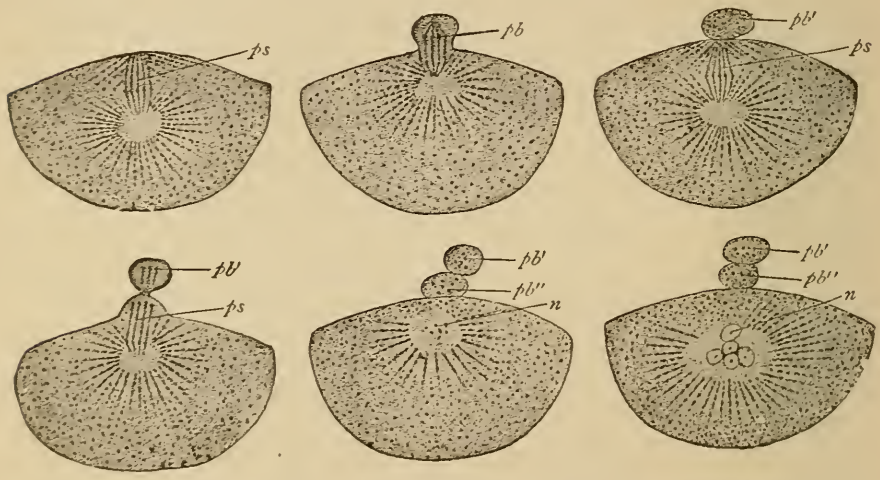


Fig. 1.—Formation of the polar bodies in the ova of *Asterias glacialis* (Hertwig): *ps*, polar spindle; *pb'*, first polar body; *pb''*, second polar body; *n*, nucleus returning to condition of rest.

have slowly but gradually taken place. This broader developmental history, or history of a race, is known as *phylogeny*. It is closely interwoven with the ontogenetic development, so much so, that the latter in large part repeats the former, or one's phylogenetic history is repeated in the ontogeny.

In development, therefore, the phylogenetic or intrinsic qualities of a cell are important factors. These factors constitute *heredity*. There is further

evidence that these factors are lodged in the chromatin of the cell nucleus.

Environment is the other great factor that brings about a structural modification. It is between environment on the one hand, and heredity on the other, that a specialization and differentiation of cells, tissues, and organs is produced.

A *cell* is a spacially limited mass of protoplasm which, under certain conditions, will assimilate, grow, and reproduce itself. A *tissue* is a complex of similarly differentiated cells and their derivatives. An *organ* is a complex of tissues, forming a body with a definite internal structure and external form.

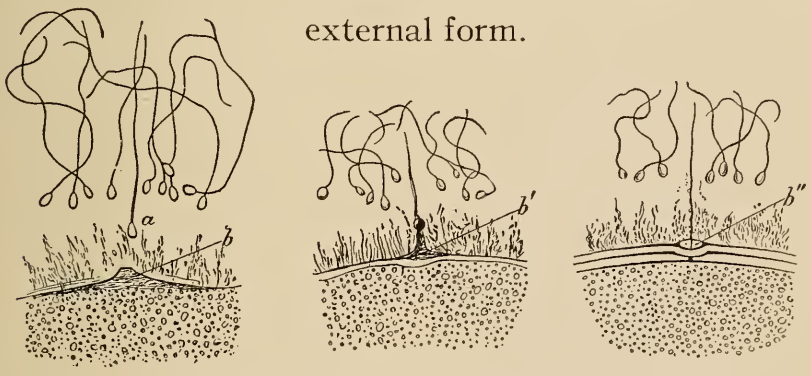


Fig. 2.—Portions of the ova of *Asterias glacialis*, showing the approach and fusion of the spermatozoön with the ovum (Hertwig): *a*, fertilizing male element; *b*, elevation of protoplasm of egg; *b'*, *b''*, stages of fusion of the head of the spermatozoön with the ovum.

Ovulation and Maturation.—The *ova* develop in the ovaries and are differentiated very early during embryonic life. The estimated number of ova in each ovary is 35,000. It is a remarkable phenomenon that for many years these units show no attempt at development or cell division. At the age of puberty one or more of these cells pass periodically from the human ovaries, approximately every twenty-eight days in the

non-pregnant woman. This process is known as *ovulation*, and continues up to the time of the menopause, which appears generally at the age of forty-five.

As soon as the ovum is liberated from the ovary, a mitotic division of the nucleus takes place, and the ovum extrudes or produces what is called the *first polar body*. This is a form of budding, the polar body receiving one-half the original nucleus of the ovum. Without delay, a second division of the nucleus in the ovum takes place, and a second polar body is produced. This is also an equal division of the nucleus, but this time there is a reduction of one-half the number of chromosomes, and may be

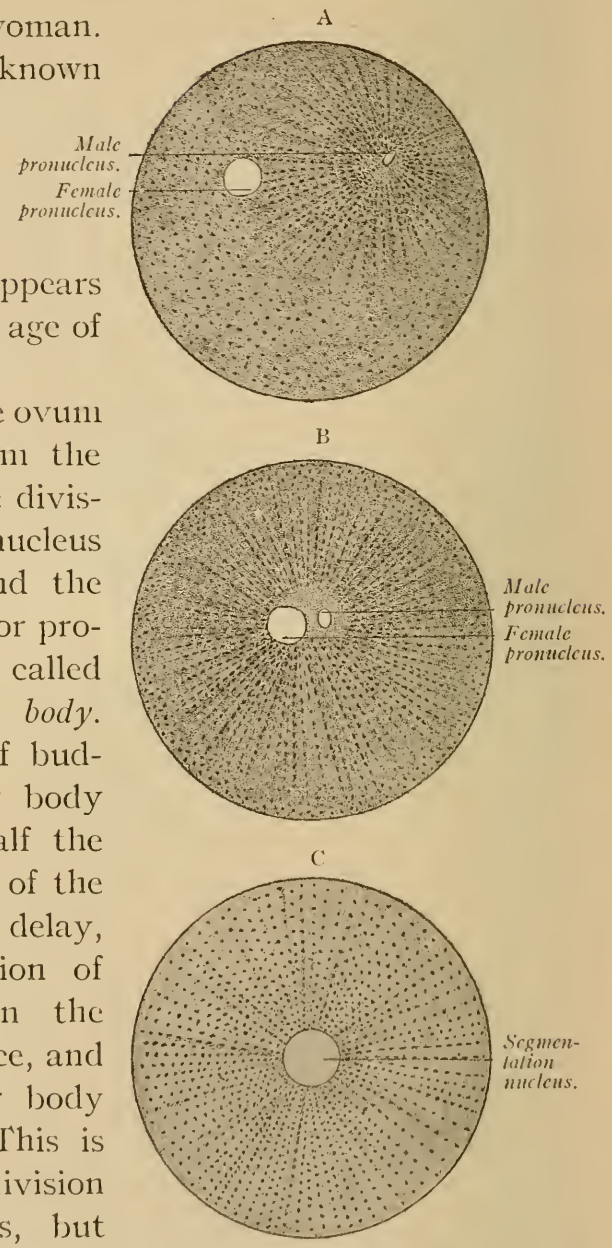


Fig. 3.—A, fertilized ovum of echinus (Hertwig): the male and the female pronucleus are approaching; in B they have almost fused; C, ovum of echinus after completion of fertilization (Hertwig).

called a *reduction mitosis*, as distinguished from all preceding and all succeeding divisions, which are called *somatic mitosis*. The significance of this reduction has led to many theories. During the process the nucleus loses its membrane, is much reduced in size, and is now known as the *female pronucleus*. All these preliminary changes are known as *maturation of the ovum*. Without fertilization, further development of the ovum does not seem possible in higher forms, and the cell is invariably lost.

Fertilization.—By this is meant the union of a spermatozoön with the ovum, or, more technically, the union of a male and a female pronucleus. This

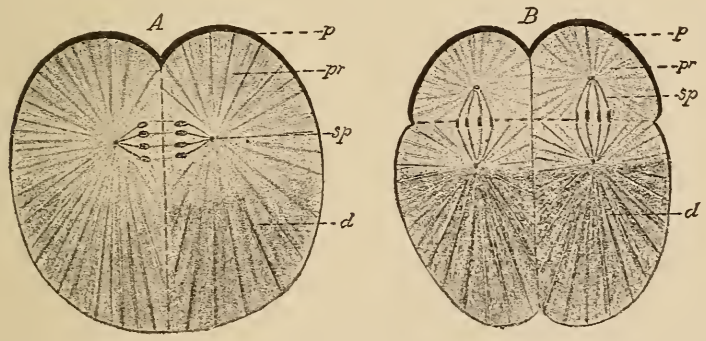


Fig. 4.—Diagram of the division of the frog's egg (Hertwig): *A*, stage of the first division. *B*, stage of the third division. The four segments of the second stage of division are beginning to be divided by an equatorial furrow into eight segments; *p*, pigmented surface of the egg at the animal pole; *pr*, the part of the egg which is richer in protoplasm; *d*, the part which is richer in deutoplasm; *sp*, nuclear spindle.

union takes place in the upper part of the oviduct. Maturation always precedes fertilization. But in lower forms experiments upon unfertilized eggs in the absence of spermatozoa have resulted in the development of embryos, or larvæ, and in a few in-

stances adult animals. This interesting result may be obtained by adding certain salts to the sea-water in which the eggs of marine animals normally develop, or in the case of the frog by puncturing with a needle the outer layer of the unfertilized egg. Professor Loeb, who inaugurated these experiments, is of the opinion that oxidation is thereby stimulated, which is followed by an accelerated protoplasmic activity that initiates a normal development of these ova without the process of fertilization. If a spermatozoön enters the ovum before the polar bodies are extruded, the spermatozoön remains inert within the cell until maturation is completed. The ovum, thus reinforced, enters upon an aggressive growth, a phenomenon quite in contrast with its preceding history.

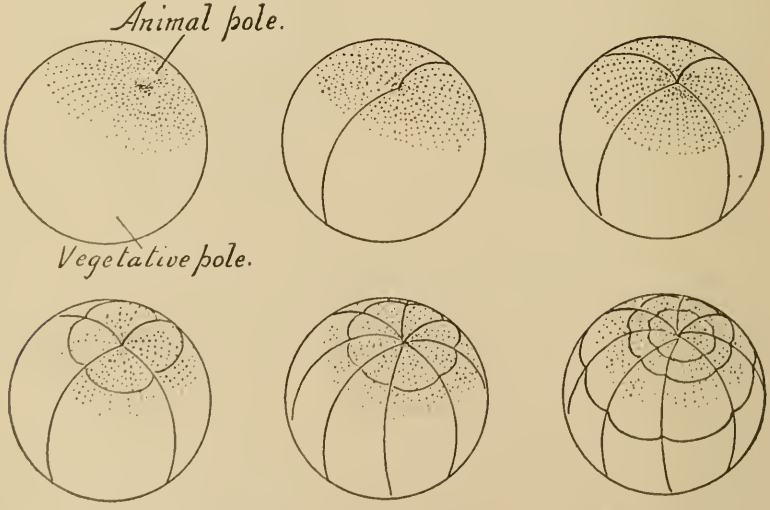


Fig. 5.—Cleavage in egg of frog, 1 to 16 cell stage.

Segmentation or Cleavage.—Following fertilization the ovum multiplies rapidly by mitosis. The

union of male and female nuclei restores the reduced number of chromosomes, which remain constant and usually even in number for every succeeding division. In certain insects an odd number of chromosomes appears, in which case the embryo develops into a male. By repeated divisions a spherical mass of cells is produced, known as the *morula stage*.

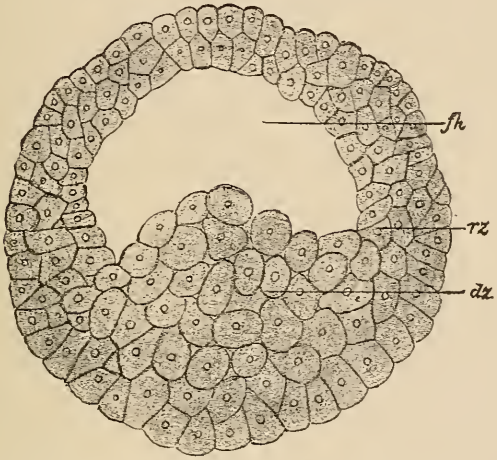


Fig. 6.—Blastula of triton tæniatus: *fh*, segmentation cavity; *rz*, marginal zone; *dz*, cells with abundant yolk (Hertwig).

Blastula.—The spherical mass quickly develops into a hollow sphere, lined by a single layer of cells, and is then a *blastula*. The cavity of the blastula is the *segmentation cavity*.

Gastrula.—A more vigorous growth seems to take place at one point of the blastula, producing lateral pressure and an invagination at that place so as to form a two-layered cup-like structure—in some eggs a blastoderm—known as the *gastrula*. The gastrulæ vary considerably according to the different forms of cleavage. It is an established fact that all metazoa pass through the morula, blastula, and

gastrula stages, respectively, in the course of their development. The cup-like cavity of the gastrula is known as the *archenteron* or *cœlenteron*, and is destined to develop into the alimentary canal. The pore or external opening of the cœlenteron is called the *blastopore*.

The gastrula has two layers of cells: an outer, the *ectoderm*, and an inner, the *entoderm*. The cells of

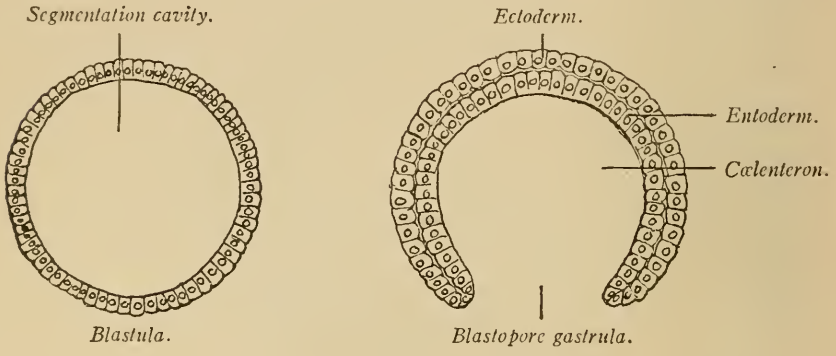
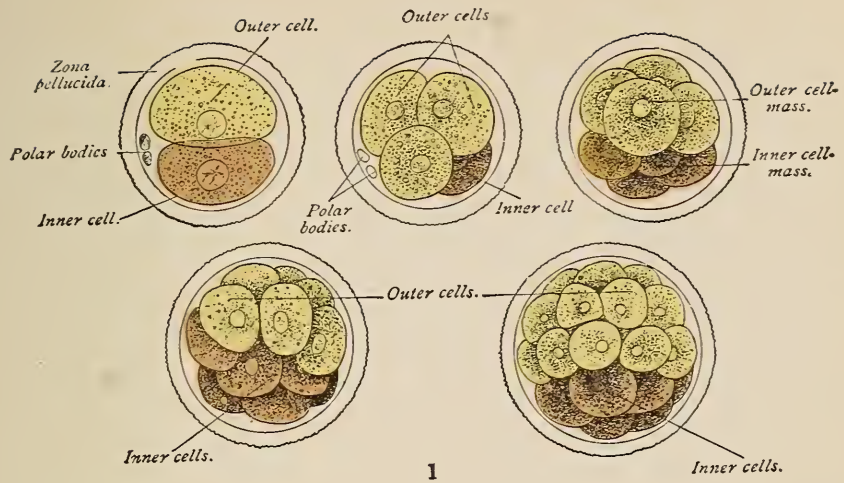


Fig. 7.—Sections through a blastula and a gastrula of amphioxus.

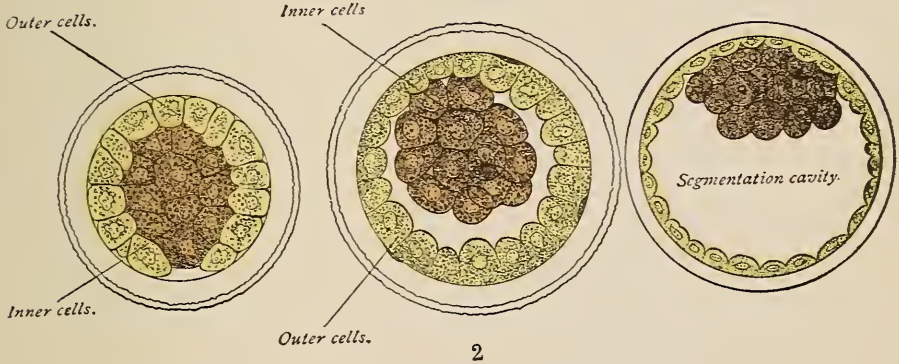
the entoderm are much larger than the cells of the ectoderm and there is thus a structural difference. In cleavage that results in a two-layered blastoderm the term *hypoderm* is used, which is thus morphologically equivalent to the *entoderm*.

The two-layered gastrula is rapidly invaded by a third layer of cells, the *mesoderm*, which develops between the first two layers and ultimately fills that cavity. This cavity, which is the segmentation cavity of the blastula, permanently disappears. The origin of the mesoderm has long been a contested question. The favored theory seems to be that for higher forms, at least, it develops from the hypoderm.

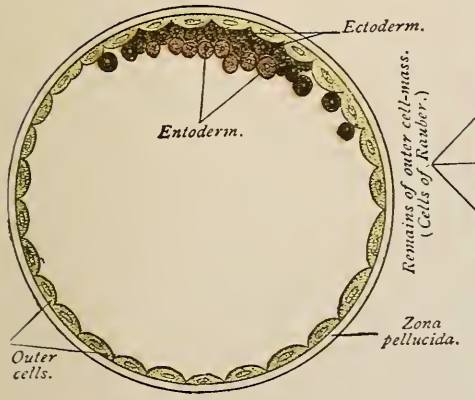
PLATE I.


Outer cell.
Zona pellucida.
Polar bodies
Inner cell.
Outer cells
Polar bodies.
Inner cell
Outer cell-mass.
Inner cell-mass.
Outer cells.
Inner cells.
Inner cells.

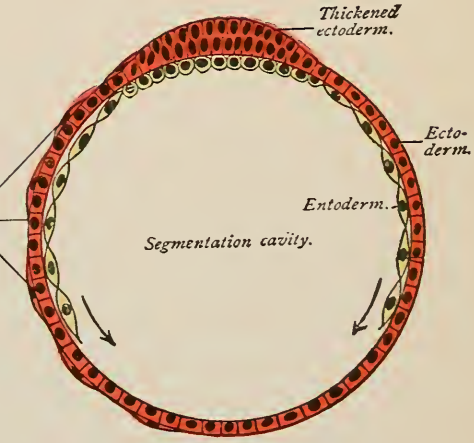
1


Outer cells.
Inner cells.
Inner cells
Outer cells.
Segmentation cavity.

2


Ectoderm.
Entoderm.
Remains of outer cell-mass. (Cells of Rauber.)
Zona pellucida.
Outer cells.

3


Thickened ectoderm.
Ecto-derm.
Entoderm.
Segmentation cavity.

4

The *mesoderm*, although at first a solid mass of cells, is an invaginated fold in which a cavity soon appears, having an inner layer of cells that affiliates closely

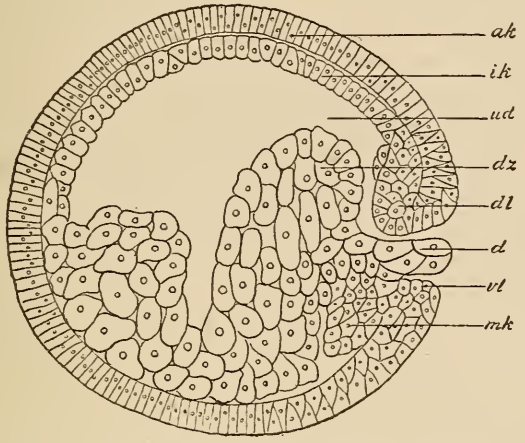


Fig. 8.—Sagittal section through an egg of triton (after the end of gastrulation): *ak*, outer germ-layer; *ik*, inner germ-layer; *dz*, yolk-cells; *dl* and *vl*, dorsal and ventral lips of the cœlenteron; *ud*, cœlenteron; *d*, vitelline plug; *mk*, middle germ-layer (Hertwig).

with the hypoderm cells, and an outer layer that applies itself to the ectoderm. The hypoderm with its mesoderm layer is known as the *splanchnopleure*, while the ectoderm and its mesoderm is the *so-*

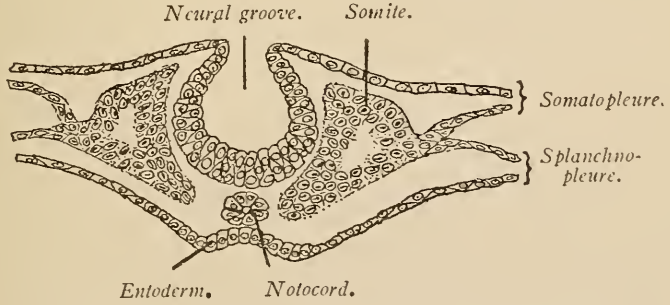


Fig. 9.—Transverse section of chick embryo 22 hours old.

matopleure. The new cavity thus produced is the

cœlom, or *body cavity*, and is destined to become the pleural and peritoneal cavities. The mesoderm on

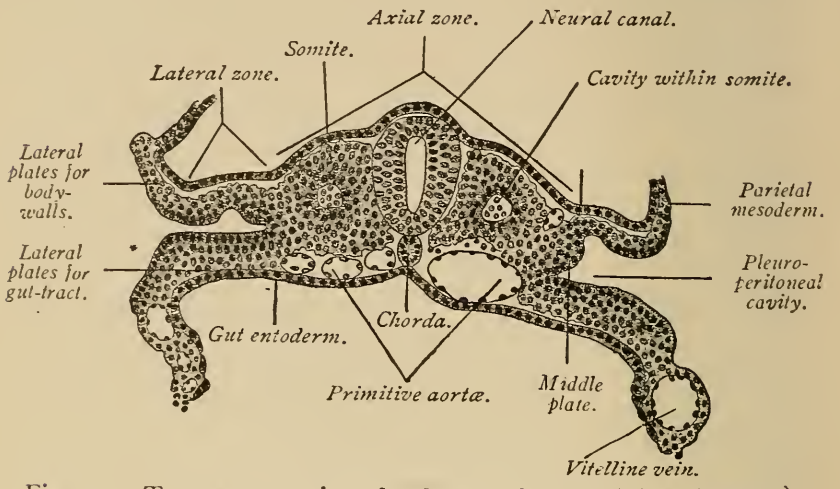


Fig. 10.—Transverse section of a sheep embryo, 17½ days (Bonnet).

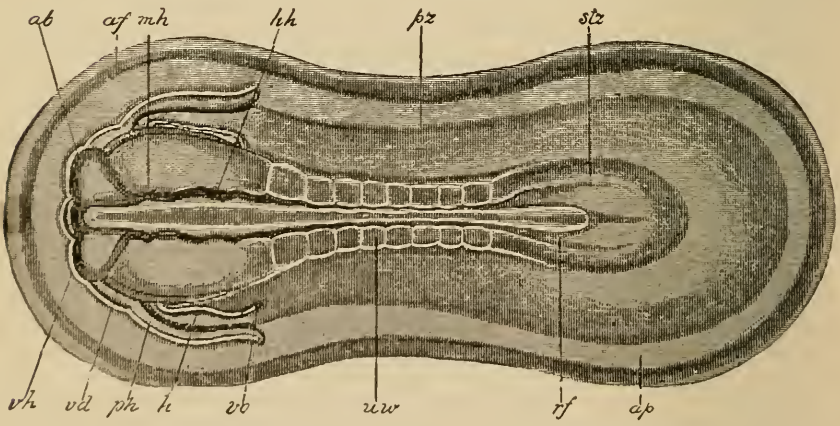


Fig. 11.—Rabbit embryo of the ninth day, seen from the dorsal side (after Kölliker). The stem-zone (*stz*) and the parietal zone (*pz*) are to be distinguished. In the former 8 pairs of primitive segments have been established at the side of the chorda and neural tube; *ap*, area pellucida; *rf*, medullary groove; *vh*, fore-brain; *ab*, eye-vesicle; *mh*, mid-brain; *hh*, hind-brain; *uw*, primitive segment; *stz*, stem-zone; *pz*, parietal zone; *h*, heart; *ph*, pericardial part of the body cavity; *vd*, margin of the entrance to the head-gut (*vordere Darmpforte*), seen through the overlying structures; *af*, amniotic fold; *vo*, vena omphalomesenterica.

each side of the neural canal becomes symmetrically

blocked by means of a longitudinal fold and many transverse folds; thus many segments or joints are produced, known as *myotomes* or *mesoblastic somites*. From these develop bone, voluntary muscle, and the dermis of the skin.

While these progressive changes are going on in the mesoderm, a longitudinal dorsal groove develops in the ectoderm. By a median fusion of the margins of the groove, it is transformed into a longitudinal canal, the *neural canal*, which develops into the *brain* and *spinal cord*.

This brief embryonic growth has been productive in specialization and differentiation of cells. In no case will the cells of one germ layer reproduce, replace, or function for the cells of any of the other layers. As derivatives of these three germ layers we are able to give the following table (Minot, "Embryology," 1903):

A. Ectoderm.	*B.* Mesoderm.	*C.* Entoderm.
1. Epidermis. (*a*) epidermal appendages. (*b*) lens of eye.	1. Mesothelium. (*a*) epithelium of peritoneum, pericardium, pleura, urogenital organs. (*b*) striated muscles.	1. Notochord.
2. Epithelium of (*a*) cornea. (*b*) olfactory chamber. (*c*) auditory organ. (*d*) mouth (oral glands), (enamel organ), (hypophysis). (*e*) anus. (*f*) chorion (fetal placenta). (*g*) amnion.	2. Mesenchyma. (*a*) connective tissue, smooth muscle, pseudo-endothelium, fat-cells, pigment cells. (*b*) blood. (*c*) blood-vessels. (*d*) lymphatics. (*e*) spleen. (*f*) supporting tissues, cartilage, bone. (*g*) marrow.	2. Epithelium of (*a*) digestive tract, esophagus, stomach, liver, pancreas, small intestine, yolk-sack, large intestine, cecum, vermix, rectum, allantois (bladder). (*b*) pharynx, Eustachian tube, tonsils, thymus, parathyroids, thyroid. (*c*) respiratory tract, larynx, trachea, lungs.
3. Nervous system. (*a*) brain (optic nerve), (retina). (*b*) spinal cord. (*c*) ganglia. (*d*) neuraxons.		

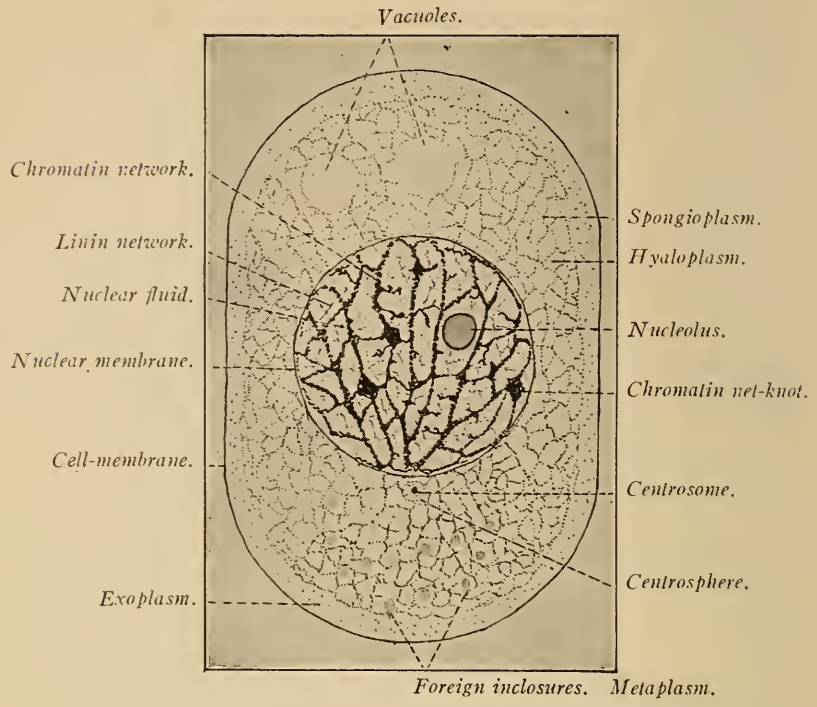


Fig. 12.—Diagram of a cell (Böhm, Davidoff and Huber).

THE CELL.

More than two hundred years ago the English botanist, Robert Hook, described cork as made up of "little boxes or cells distinct from one another." In 1838 Schleiden postulated a cellular basis for plants, and according to his conception these cells were minute compartments filled with a fluid substance in each of which floated a nucleus. The following year, 1839, Schwann showed that the animal body was likewise built up of cells resembling those described by Schleiden in plants. These observations placed animals and plants on a common structural basis and established the *cell theory*, now regarded as one of the great biological discoveries of

the eighteenth century. Von Mohl in 1846 recognized in these cells a viscid, semifluid, granular substance which he named *protoplasm*. Meanwhile extensive observations by other scientists demonstrated the existence of cells without cell walls, all of which prepared the way for Max Schultze, who in 1861 showed conclusively the identity of protoplasm in all life, establishing the *protoplasm theory*, another great biological discovery of the eighteenth century. The conception of a cell, as postulated by Schleiden and Schwann, thus became modified, so that today this biological term stands for a nucleated mass of protoplasm which under certain conditions is capable of assimilation, growth, and reproduction. In some cells, as certain bacteria, no nucleus has been found; however, in animal tissues as a rule, the nucleus is constantly present and forms an essential part of the cell. Whenever the nucleus is lost or destroyed, the cell dies.

Protoplasm.—Wherever we find protoplasm we find life, and wherever we find life we find protoplasm. Protoplasm is not life, but all agree it is the physical basis of life. Every particle of protoplasm has its origin in some antecedent protoplasm, and so on, in an unbroken series, all life is traced back to the earliest primitive form of protoplasm. This protoplasm is a viscid, transparent, jelly-like substance. It is not a substance of uniform physical and chemical properties, but a mixture of many organic compounds which in many ways resemble the proteid bodies or the albumins. It is insoluble in water, but absorbs water in variable quantities. The protoplasm of dry seeds may contain but three or four per cent. of water, while

in parenchymatous or young growing tissues we may find ninety-five per cent. of water. The phenomenon of motion is common to all protoplasm. In plant protoplasm a streaming process is manifest, which shows considerable regularity as to the direction of the current within the cell. This motion, as well as physiological activities, is greatly modified by change in temperature, and its activities are also very sensitive to change in intensity of light and even to the different colors of light as well as to the actinic rays. It is therefore irritable in the highest degree.

Cytoplasm is the name given to the protoplasm of the cell body or that which surrounds the nucleus. The cytoplasm exhibits (1) a fine reticulum of anastomosing or interlacing threads or plates of varying complexity called *spongioplasm* or *fibrillar mass*. These threads are probably composed of small particles or granules, named *microsomes*, that are in close touch with each other and arranged in rows. The other constituent of cytoplasm is (2) a fluid substance lying between the meshes of the spongioplastic reticulum, and has been called *hyaloplasm*, *paraplasm*, or *cytolymph*. Recent observations indicate that the microsomes are primarily derived from the nucleus and constitute the more important vital parts of the cell.

In some cells the microsomes are so placed as to give a foam-like structure to the cytoplasm rather than a reticular appearance. Again, the cytoplasm of certain cells has a homogeneous watery appearance devoid of any definite structure. There are therefore three theories as to the structure of protoplasm:

1. That it is a fluid homogeneous substance.

2. That it consists of minute spherical globules, like an emulsion.

3. That it is a mass of interlacing fibrils, forming a complex reticulum.

In many cells the protoplasm, at or near the surface, is quite dense, forming what is then called the *ectosarc*. The more vicsid central portion is the *endosarc*.

In the cytoplasm, usually by the side of the nucleus, a small body may be found in most cells, called the *centrosome*. The centrosome is occasionally in the nucleus and but little larger than a microsome, being usually surrounded by a clear, radially striated area of protoplasm called the *attraction sphere*. The centrosome takes an active part in the multiplication of cells, but otherwise its function is problematic.

The cell wall is to be regarded as a cell product. In plant tissues the cell wall is relatively thick and composed largely of cellulose. In animal tissues the cell wall is unusually thin, often difficult to demonstrate, and in many cases absent. Examples of the latter are amœbas, white blood corpuscles, nerve cells, and probably liver cells.

Nucleus.—The nucleus is the second constituent of the cell and is a round or an oval protoplasmic body found floating in the cytoplasm. Its shape usually corresponds to the form of the cell, but occasionally C-shaped, ring-shaped, and even branched nuclei are found. Its position may be eccentric or at one end of the cell. It has more consistency than the cytoplasm, but is plastic and displays consider-

able elasticity. Independent movement of the nucleus in the cytoplasm has often been observed. At the same time its relation to the cytoplasm is a most intimate one and many cytoplasmic particles doubtless have their origin in the nucleus.

The structure of the nuclear protoplasm is even more complex than that of the cytoplasm. A reticulum of coarse, thread-like texture is constantly present. This stains deeply and is therefore called *chromatin*. The chromatin threads, like the spongioplasm of the cytoplasm, are made up of minute particles or granules compactly arranged in rows that cross and interlace, making nodal points here and there called nuclear net-knots. The chromatin is imbedded in or deposited on a less stainable reticulum called *linin*, and surrounding both chromatin and linin everywhere, and filling their meshes, is a semifluid substance that does not readily stain and is therefore called *achromatin*, *nuclear sap*, *paralinin*, or *karyolymph*.

Imbedded in the achromatic substance are one or more spherical bodies called *nucleoli*. The nucleoli stain less heavily than the chromatin and may be dissolved by reagents that do not affect the chromatin; therefore, they are composed of a substance not identical with the latter. Their function is not known. The nucleus is usually enclosed in a thin *nuclear* membrane (amphipyrenin) not unlike chromatin material. This membrane has perforations which allow a free communication between the achromatic fluid of the nucleus and the cytolymph and

establish a most intimate relation between nucleus and cytoplasm.

Cell Inclusions.—Bodies of a solid nature, not protoplasmic, are common to many cells. These are pigments, oil, fat, crystals, glycogen, starch, chlorophyl, etc., and are spoken of as *cell inclusions*. The last two are found almost exclusively in plant cells. By these inclusions the shape of the cell is often changed, and particularly the position of the nucleus. Fat gathers at one end of the cell, crowding the nucleus to the opposite extremity and displacing the cytoplasm to the periphery, mostly to that end of the cell occupied by the nucleus. Pigment may be in solution, more frequently in granules, and always in the cytoplasm, not in the nucleus. *Vacuoles* are very common to most cells. These vary in number and size and are usually spherical cavities filled with fluid secreted by the protoplasm. The vacuoles contract, often with considerable regularity, and, as a rule, empty to the surface of the cell. Waste products are in this way eliminated from the body of the cell.

The constituents of a typical cell may then be summarized as follows:

1. *Cytoplasm*, the protoplasm that surrounds the nucleus, consisting of,—

(*a*) Spongioplasm, a reticulum or fibrillar network;

(*b*) Hyaloplasm, a fluid portion, also called cytolymph;

(*c*) Cell membrane, often absent in animal cells.

2. *Nucleoplasm* or karyoplasm, the protoplasm of the nucleus,—

(*a*) Nuclear membrane, frequently absent;

(*b*) Chromatin, network that stains easily;

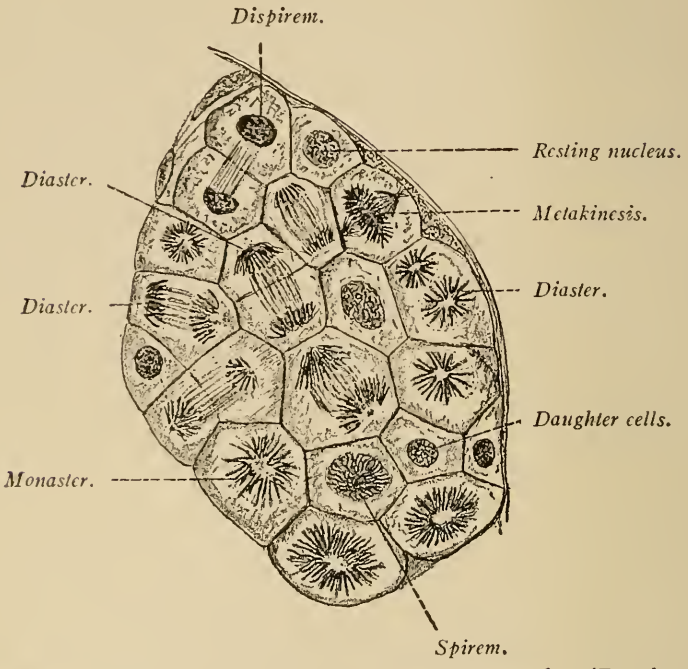


Fig. 13.—Mitotic division of cells in testis of salamander (Benda and Guenther).

(*c*) Linin, closely applied to the chromatin, does not stain; dissolves in distilled water;

(*d*) Nuclear sap, a fluid perhaps analogous to the hyaloplasm;

(*e*) Nucleolus, spherical body that stains heavily;

(*f*) Nuclear net knots, or karyosomes, false nuclei that are nodal points formed by interlacing chromatin network;

(*g*) Nuclear membrane, amphipyrennin;

(*h*) Centrosome, a small spherical body often found in the cytoplasm near the nucleus. It is looked upon as the dynamic center in cell division.

Mitosis or Karyokinesis.—*Mitosis* is indirect cell

division, and refers to the changes manifest in the nucleus during such division. The process may be divided into four phases—

1. *Prophase.* The first manifestation of mitosis appears in the centrosome. This little body is, therefore, looked upon as the dynamic center of the cell. The centrosome divides and each half passes to opposite poles of the nucleus. The chromatin network, which really consists of chromatin granules, is transformed into a skein of threads known as a *spirem* or *mother skein.* These threads break up into a definite number of segments known as *chromosomes.* The chromosomes are even in number, and, for a given species, a constant number is always present. In the human cell there are sixteen chromosomes,—according to some, twenty-four. Toward the close of this stage, each chromosome forms a loop and is finally arranged symmetrically around the equator of the nucleus, with the free ends of each loop turned away from the center. This symmetrical figure is known as *monaster.* During this stage the nuclear membrane usually disappears. The nucleolus also vanishes, just how is not clear. The net knots disappear with the formation of chromatin loops.

During these changes the achromatic substance—linin and nuclear sap—has formed a central spindle with each apex directed toward a centrosome. This spindle consists of fine threads or lines directed toward the centrosomes. A like radiation becomes manifest in the cytoplasm, each line being directed toward, or from, one or the other centrosome. This

radiation is absent from the protoplasm immediately surrounding each centrosome, forming a clear field called the *attraction sphere*. The lines that extend

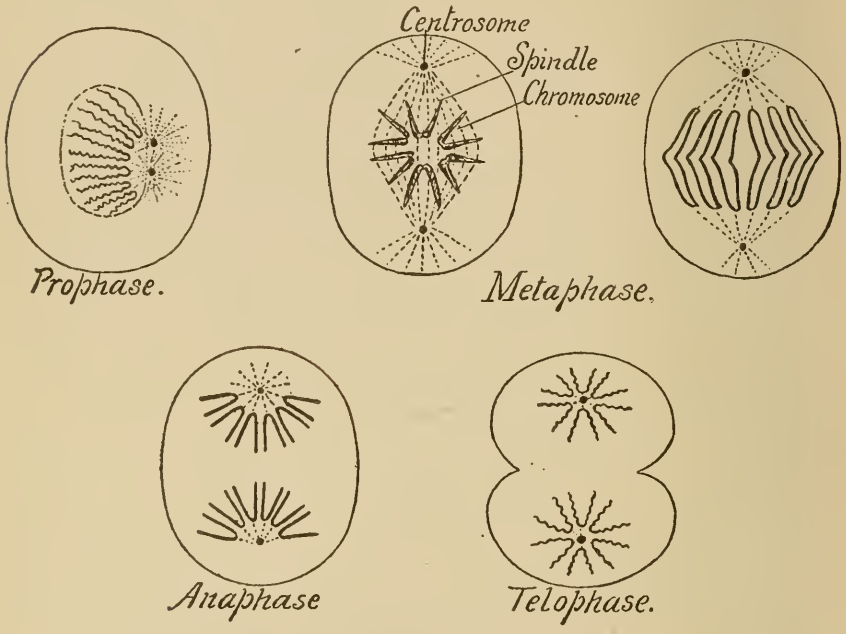


Fig. 14.—Diagram of mitosis.

into the cytoplasm are known as *polar rays*. Those that form the spindle seem to be attached to the curved portions of the chromatin loops.

2. *Metaphase.*—This stage begins with the chromatin loops arranged radially in the equatorial plane of the nucleus. The most important change in mitosis now takes place, in that each *chromosome loop* divides lengthwise to form two *daughter chromosomes*. This is an equal division, both qualitative and quantitative. The curved portion of each daughter loop passes along the rays of the achromatic spindle and approaches one or the other cen-

trosome. There are three theories as to the mechanism involved:

(1) It is affirmed that the threads of the spindle contract and pull each daughter loop toward its centrosome.

(2) The rays or threads may elongate and push each loop toward the opposite centrosome. According to this theory there should be twice as many lines or rays between the loops as there are spindle rays from each centrosome, an observation recorded by some investigators.

(3) The centrosomes may be fermenting centers of chemical change, and the explanation, therefore, a chemical attraction or affinity.

At the close of the metaphase the daughter loops arrange themselves respectively around each centrosome forming what is known as a *diaster or daughter star.* The free ends of these are turned away, and the curved portions of each are turned toward the centrosome.

3. *Anaphase.*—During this period the changes manifest in the prophase are reversed. The chromatin loops are gradually transformed into twisted skeins of threads, called *daughter skeins*, which ultimately produce the normal chromatin reticulum. The nuclear membrane and nucleolus reappear. A constriction of the cytoplasm is manifest for the first time. This constriction appears in the plain passing between the daughter nuclei.

4. *Telophase.*—In this stage the cell divides completely. Each daughter cell gradually assumes the normal condition of the parent cell from which it had

its origin. The time required for complete division varies from one to several hours.

Amitosis is the direct cell division and occurs seldom as a normal process. The nucleus merely constricts, without the formation of chromatin loops or filaments, thus producing two or more nuclei or nuclear fragments. The cytoplasm may not take part in this division, in which case polynucleated cells are formed; however, polynucleated cells may also arise from mitosis. Preceding the division the nucleolus, if present, may subdivide, while the centrosome does not seem to take any active part whatever. In the human body certain leucocytes have been described as dividing by amitosis, also polynucleated pavement cells of the bladder. Degenerated cancer cells have been described as showing amitotic division, but whether a cause or a consequence of degeneration and disease can be argued with equal force. On the other hand, certain embryonic cells have been described as dividing by amitosis, which later take up the regular cell division of amitosis, but these cases, if normal, must be regarded as very exceptional.

Laws of Cell Cleavage.—(1) The cleavage plane is always equatorial to the nucleus.

(2) The position of the nucleus depends on (*a*) the shape of the cell, and (*b*) on the distribution of food material or secretions. If the cytoplasm is eccentric in the cell, the nucleus is associated with it.

(3) When each plane of division is parallel to the preceding plane, a filament is produced. This is the law in some plants, as *spirogyra*, *nostoc*, etc.

(4) When each plane is at right angle to the preceding plane and in two dimensions, a surface of cells is formed, as simple epithelium.

(5) When each plane is at right angle to the preceding plane and in three dimensions, a volume or an organ is formed with three dimensions, as the morula stage in embryos.

General Considerations.—The subject of cell division has given rise to much discussion. While we are unable to control mitosis, the following are factors that modify cell growth:

1. *Trauma.*—Following a cut or a bruise the adjacent cells are stimulated to rapid multiplication and the wound heals.

2. *Heat.*—There is a mean temperature for the maximum multiplication of cells which varies with the species. In man this mean temperature is blood heat, 98.6°.

3. *Electricity.*—By stimulating protoplasmic activity, electricity no doubt is a factor in influencing normal cell growth. Just how this is accomplished, and to what extent, is a much-disputed problem.

4. *Light.*—A very important factor in promoting multiplication, or decreasing it, or even destroying certain cells, as bacteria. The different rays of light have each a specific effect.

5. *Nourishment.*—Proper food is a stimulant.

6. *Chemical.*—Certain salt solutions, as sodium and potassium salts, have a stimulating effect.

7. *Exercise.*—Regular systematic exercise prompts a healthy growth. Massage acts in the same way. A laborer, after a day of toil, is exhausted because

his cells are depleted and some of them actually lost. During his period of rest new cells are built up from the ingested foods and thereby, practically, new tissues are formed, giving the feeling of comfort and increased vigor. The acquisition of new tissues is an asset and should be encouraged.

Pathological tumors are abnormal growths of normal tissues. In many of these tumors the cells multiply rapidly by mitosis, resulting often in unequal division of the chromosomes, or chromatin loops, but whether this is a cause or a consequence can be argued with equal force. We are unable to produce these tumors experimentally, and, unfortunately, we are often unable to stop their multiplication of cells.

The surface of a sphere increases as the square of its diameter, while the volume increases as the cube of the diameter. As the cells depend upon their surface area for the absorption of food and elimination of waste, and as the volume increases at a greater rate than the surface area, the reduction in size of a cell becomes a necessity.

Much significance is attached to the fact that mitosis brings about an equal division of the chromatin or chromosomes. If for any reason an unequal division obtains, the cell becomes abnormal and a monstrosity, with death, follows. Experimentally this may be done with an egg cell, which, if anesthetized, allows more than one spermatozoön to enter, resulting in an unequal division of the female pronucleus and an abnormal development. That chromatin is the bearer of hereditary qualities is a postulate based upon the observation that mitosis

results in an equal division of the chromosomes. What these unrevealed biological units are is a matter of much controversy.

Much work has been done in recent years on the individuality of the chromosomes, establishing the fact that they vary greatly in size, form, and constituents in one and the same cell. Some are long and some are short, thick and slender, greatly curved and nearly straight, stain dark or take only a slight stain; in short, we must now admit their personnel and postulate special cell function for each chromosome. Moreover, it is now practically established that certain spermatozoa, particularly in insects, have an odd chromosome, and that from eggs fertilized by this particular class males develop, whereas from fertilization by spermatozoa having an even number of chromosomes females are produced. In a species of insect, *Lygæus bicrucis*, the males develop spermatozoa that have all the same number of chromosomes, but in one set there is present one large chromosome and in the other set there is present one small chromosome. If a spermatozoön with the small chromosome fertilizes the egg, a male develops, and if one with the large chromosome fertilizes it, then a female is formed. Sex chromosomes have now been recognized in a large number of males of different groups of animals, and we can, therefore, safely affirm that the determination of sex rests, in most cases, with the intrinsic quality of the fertilizing spermatozoön. Morgan, therefore, concludes that "if these observa-

tions are confirmed they show that in man, as in so many animals, an internal mechanism exists by which sex is determined. It is futile then to search for environmental changes that might determine sex." ("Heredity and Sex," page 248, Columbia University Press, 1913.)

CHAPTER II.

TISSUES.

A tissue is a complex of similarly differentiated cells and their derivatives. In all embryonic tissues and some adult tissues the cell elements predominate, but in cartilage and bone and many connective tissues the cell products make up the bulk of the tissue. There are four kinds of elementary tissues,—(1) *epithelial tissue;* (2) *Supporting tissue;* (3) *Muscular tissue;* (4) *Nerve tissue.*

I. EPITHELIAL TISSUE.

Epithelium lines surfaces, external and internal, and forms the secreting cells of glands. (See table, page 33.) The cells of this tissue are derived from any one of the three germ layers. Blood and lymph vessels do not penetrate between the epithelial cells, but nerve fibers enter the deeper strata and end in minute varicosities that lie in contact with many of the cells. The cells have a regular form, a thin cell wall, and a distinct nucleus that is rich in chromatin and therefore stains easily with hematoxylin. They usually secrete a cement found between adjacent cells which serves the purpose of holding each cell firmly in place. The cell wall is usually smooth, but in certain places the lateral walls develop many short, minute processes (prickles) that meet like processes from adjacent cells, forming *intercellular bridges,* and between the latter are found *intercellular spaces* filled with nourishing fluid for the individual cells. The

cell rests upon a basement membrane that is usually considered to be made up of basal processes of the basal cells.

The free surfaces of epithelial cells may develop cilia, which serve the purpose of sweeping away fluids or foreign bodies. In many instances a delicate lining called the *cuticle* covers the free ends. The cuticle is to be regarded as a cell product, and since in many cases a fine transverse striation can be seen, it seems probable that the cuticle is built from a large number of transverse rods cemented

Fig. 15.—Epithelial cells from skin of frog. Surface view of external layer.

together. In columnar cells the nucleus is usually found at the basal end, thus being placed nearer the blood and lymph supply, the nourishing cell media.

Epithelial tissue is classified as: (1) *simple* or (2) *stratified*.

1. **Simple epithelium,** consisting of a single layer of cells.

(*a*) *Simple squamous*, flat single layer of cells, found in the alveoli of the lung and in Bowman's capsule of the kidney.

(*b*) *Simple cuboidal,* found forming the wall of small ducts, portions of the kidney tubules, and the vesicles of the thyroid gland.

(*c*) *Simple columnar,* ciliated or non-ciliated.

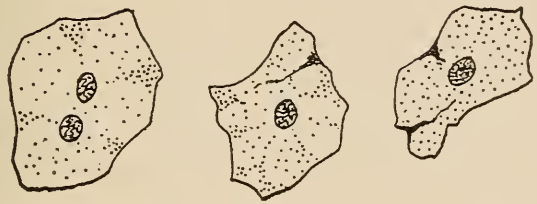


Fig. 16.—Squamous epithelial cells from the mouth.

This is the most common form of simple epithelium. The alimentary canal, below the diaphragm, has simple columnar; also portions of the kidney tubules.

Fig. 17.—Simple columnar cells from intestine.

Simple ciliated is found in the oviduct, uterus, central canal of the spinal cord, and smaller bronchi.

(*d*) *Pseudo-stratified.*—In this type all the cells rest on a common basement membrane, but the nuclei rest at different levels, which give the tissue the appearance of being stratified. Frequently this tissue is ciliated, as is the case in portions of the respiratory tract.

2. **Stratified epithelium,** consisting of several layers of epithelial cells.

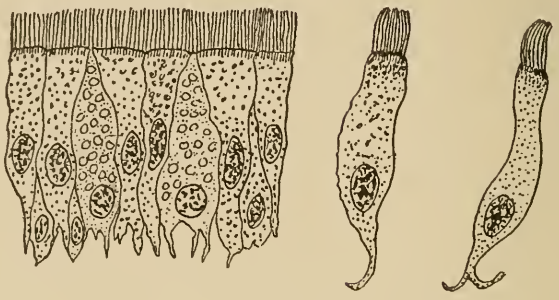


Fig. 18.—Ciliated epithelium from trachea.

(*a*) *Transitional,* consisting of two or three layers of cells, found in the wall of the bladder, ureters, pelvis of kidney, and prostate portion of male urethra. In this case the surface layers of cells are

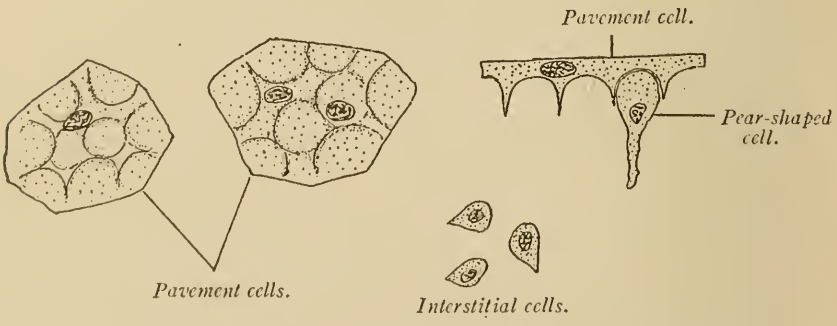


Fig. 19.—Epithelial cells from the bladder.

flat, often polynucleated and form a mosaic pattern upon the second layer, which is pear-shaped, with the broad ends forming depressions into the first layer of cells. The third layer consists of smaller, irregular, interstitial cells that fill the spaces between the pointed ends of the second row.

(*b*) *Stratified Squamous.*—In this case the superficial layers are flat and the deeper ones cuboidal

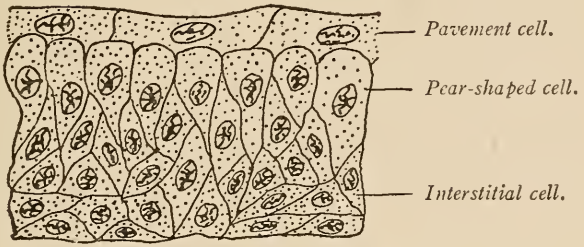


Fig. 20.—Section of bladder epithelium.

or columnar. This is the most extensive of the epithelial tissues. It forms the epidermis of the skin, the walls of the oral cavity and the esophagus, the epithelium of the conjunctiva, external auditory canal, vagina, and the external sheath of hair follicles.

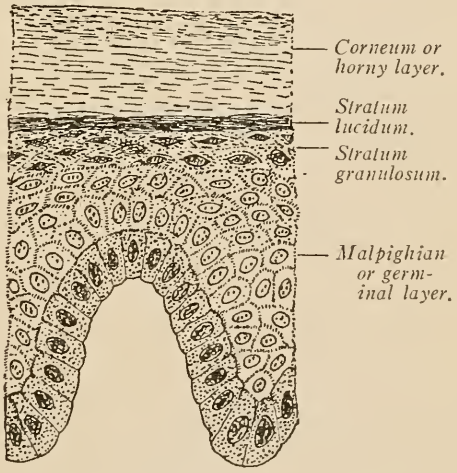


Fig. 21.—Section of epidermis of skin from palm-surface of finger.

The outer cells become horny and scale away quite regularly in thin lamellæ. The deeper layers are arranged to form papillæ that interlock with connective tissue papillæ and thus not only anchor the epithelium to the subjacent tissue, but increase the absorbing surface by approximating a larger number of epithelial cells to the underlying blood and lymph capillaries.

(*c*) *Stratified columnar*, ciliated or non-ciliated. This is found in the olfactory mucous membrane, the first part of many gland ducts, palpebral conjunctiva, portions of the male urethra, vas deferens, and portions of the larynx.

General Considerations.—The epithelial cells are simpler and more embryonic than the cells of the other tissues. They are continually multiplying throughout life, to replace the superficial layers that are constantly exfoliating from the surfaces. If any of these surfaces are injured, the cells marginal to the injury repair the loss by a gradual growth covering the denuded surface. As a consequence of this mitotic activity, we find these cells frequently in pathological growths as epithelial growths or epithelioma. If the tumor is malignant it is a carcinoma or cancer. It is a remarkable fact that, in the adult, epithelium is able to produce cells only of its own kind,—*i. e.*, squamous cells produce squamous epithelioma, and columnar cells columnar epithelioma. Epithelial tissue, however, is easily modified, as is evidenced by calloused hands, produced by heavy labor, and the cornification of nails, hair, horns, and teeth.

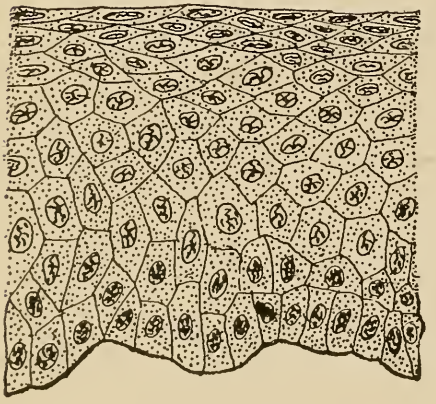


Fig. 22.—Section of stratified epithelium from esophagus.

Since the blood supply never penetrates epithelial layers, it is evident that the superficial layers of cells receive less nourishment and ultimately die, which, perhaps, accounts for the constant exfoliation. It is also evident that anything that will increase the blood supply will increase the nourishment, as friction, massage, and hot applications. The nourishment, at best, is not very good, which explains the

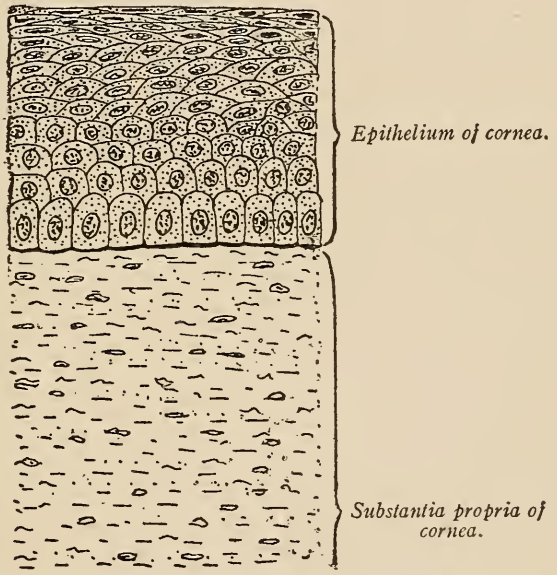


Fig. 23.—Section showing corneal epithelium of the eye of pig.

ease with which skin grafts are made. Epithelial cells will live for twenty-four hours or more in normal salt solutions, and will even multiply in favorable culture media.

The nerve termination among the epithelial cells is an important relation which, in large part, controls their metabolism. A disturbed nervous system may impair or even cause a destruction of epithelial cells.

Cilia are exclusively confined to epithelial cells. There are three theories to account for the motion of cilia:

1. The contraction may be intrinsic in the wall of the cilium. This theory is supported by the fact that the cilium or flagellum of a spermatozoön will show motility when severed from the rest of the cell.

2. Contraction of the base where the cilia are attached. The cilia will continue to vibrate if a fragment of the cell protoplasm remains attached to them.

3. The cilia are supposed to be hollow tubes with walls of unequal elasticity. By forcing the protoplasm rapidly into these tubes ciliary motion is produced. Pseudopodia are produced in this manner, and the morphological relation of pseudopodia and cilia is a close one.

The one great physiological action of epithelium seems to be to secrete fluids. Consequently epithelium is found lining all cysts wherever the cyst is located,—in the ovary, the skin, or in connection with the alimentary tract. Conversely, a cyst may be formed wherever epithelium is found.

Lastly, it is of the greatest importance that students should be able to recognize epithelial cells. The facts to be remembered are:

1. That they line surfaces.

2. That they appear in compact layers.

3. The oval or round distinct nucleus, usually rich in chromatin.

4. The regularity of the cells, *i. e.*, they are of one pattern, either squamous, columnar, ciliated, or cubical.

5. They stain deeply with nuclear stains.
6. Their chief function is to secrete.
7. The absence of blood- and lymph-vessels.
8. The presence of free nerve endings. While this is of no diagnostic microscopic value, it is physiologically an important relation to bear in mind. In wounds and old sores the epithelial border is the most sensitive part and should be carefully manipulated to avoid inducing pain.

Glands.—Much literature has been contributed the last years relative to the proper conception as to what constitutes a gland. The prevailing opinion seems to be that any structure which secretes or puts out a product that is not used directly in the metabolism of the body should be called a gland. If the fluid is a waste, the product is an excretion; if it has a utility, it is a secretion. Accordingly, mucous and synovial and serous membranes are glandular structures as well as the liver, the pancreas, or the kidney. Furthermore, the simplest form of a gland is a single secreting cell situated apart by itself, and such *unicellular glands* are quite common in invertebrates and are represented in man by the goblet cells found in mucous membranes. Epithelial cells are the chief secreting cells of the body, and these cells, therefore, form the glandular tissue of all glands except the *lympho-glandulæ*, which is a connective-tissue production. The lymph glands thus constitute a class entirely by themselves as distinguished from all other forms, which may be called *epithelial glands*. As one of the important functions of lymph glands is to contribute white blood-corpuscles and thus scatter its

own cells, they may also be called *dehiscent* or *cytogenic glands*, a term applicable to the testes and ovaries, which are epithelial glands that perform a similar function by putting out their own cells in the form of *spermatozoa* and *ovules*.

Numerous *goblet cells* are found in the simple epithelium lining the stomach and intestines, and are particularly abundant in the lower part of the bowel. These cells function as glands and secrete mucus for the protection of the surface. In case of irritating media, such as undigested food or poisons, extensive mucus is poured out over the surface, thus protecting the delicate inner lining. In some cases of constipation this mucous secretion is impaired. Salts or drugs that increase the functional activity of these cells correct such complication. On the other hand, too extensive a secretion may be corrected by drugs, as opiates, that inhibit the physiological action of these cells. Constipation may be due to inertness of the musculature of the intestinal wall, in which case other remedies correcting this disturbance are indicated—massage, hydrotherapy, and drugs that act on the musculature.

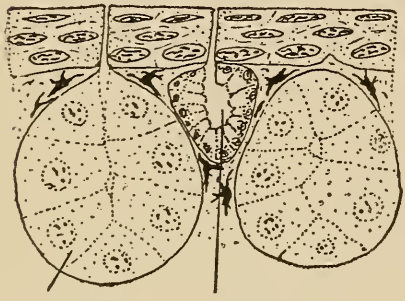


Fig. 24.—Skin and simple alveolar glands from the salamander.

Physiologically, many gland cells are either mucous or serous. In mucous cells the mucus secretion collects at one extremity of the cell as a clear, glisten-

ing drop. The cytoplasm and nucleus are crowded to the opposite end. In serous cells the nucleus is more centrally placed, and the serous secretion is stored up as minute granules distributed throughout the cytoplasm, more especially in that portion of the cell lining the free surface. Some

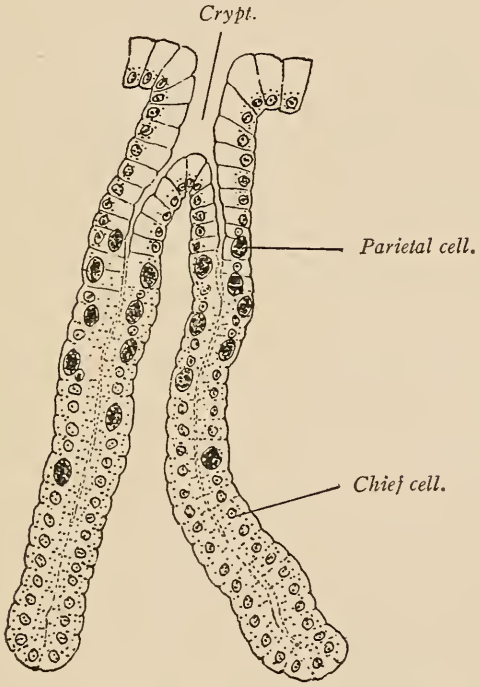


Fig. 25.—Simple tubular gland from stomach.

glands are mucous, some are serous, and some are mixed.

Mucous Membrane.—A mucous membrane consists of a lining of epithelial cells, basement membrane, and membrane propria. The basement membrane is largely an elastic cellular secretion on which

the epithelial cells rest, although at times flattened connective-tissue cells seem to enter into its formation. The membrana propria is a connective-tissue production consisting of connective-tissue cells, fibers, and blood- and lymph-vessels. Mucous mem-

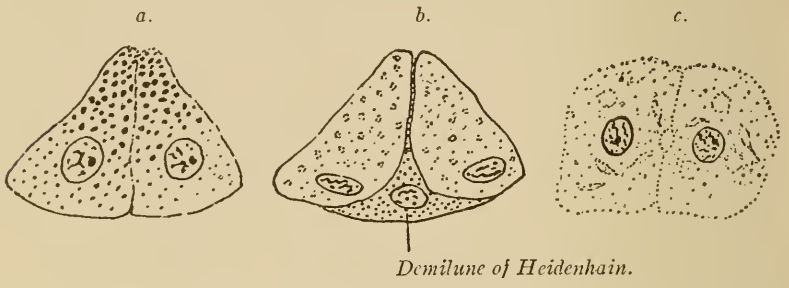


Fig. 26.—Cells from different glands: *a*, Pancreas; *b*, submaxillary gland; *c*, liver.

branes line cavities or tubes that communicate with the surface of the body, such as the alimentary canal, respiratory tract, and urogenital system.

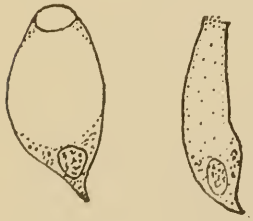


Fig. 27.—Goblet or mucous cells from intestine.

Serous Membrane.—A serous membrane has the same histological elements as the mucous membrane. The epithelial lining is simple squamous, and these cells secrete a serous fluid, more viscid and more of a lubricant than mucus. Serous membranes enclose cavities that do not communicate with the surface of the body, as the pleural, pericardial, and peritoneal cavities and cavities of joints, forming in the latter case synovial membranes. Sheaths or bursæ of tendons have serous membranes.

As to form, epithelial glands are classified as—

1. *Simple.*

(*a*) *Simple tubular*—gastric glands, sweat glands, and uterine glands.

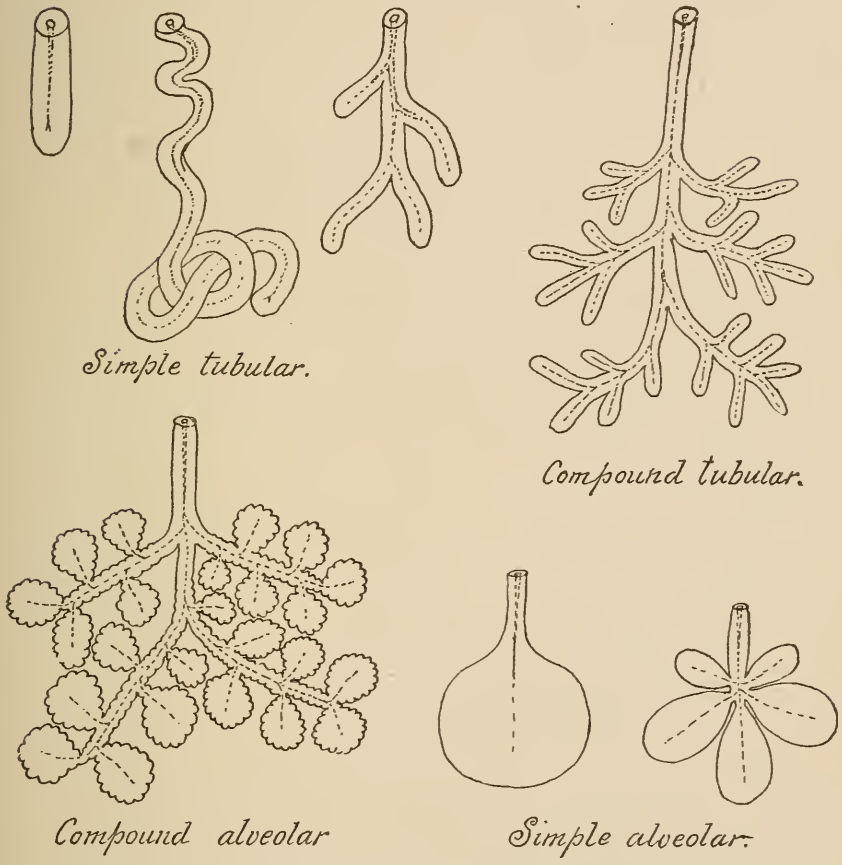


Fig. 28.—Diagram of different forms of glands.

(*b*) *Simple alveolar*—smallest sebaceous glands, and skin glands in amphibians.

2. *Compound.*

(*a*) *Compound tubular*—kidney, liver, testis.

(*b*) *Compound alveolar or racemose*—salivary glands, mammary gland, lung, pancreas, sebaceous glands.

Glands not included in this classification are *unicellular glands* and *secreting membranes*, which cannot be classified as to form. *Lymph glands*, which are of connective-tissue origin, and like the testis or ovary, may be called *dehiscent* or *cytogenic glands*. *Follicular glands*, such as the thyroid gland, and the *ductless glands*, producing internal secretions, such as the *hypophysis cerebri*, *thyroid gland*, *suprarenal gland*, *areas of Langerhans* of the pancreas, *interstitial cells* of the testis, and *corpora lutea* of the ovary. The thymus gland and spleen are lymphoid organs, and therefore to be classified among the *lymphoglandulæ*.

The object of any anatomical classification is to simplify and correlate structural facts. From the foregoing outline it is clear that *glands*, according to modern views, embrace such a complex of structures that any classification, either according to origin, or form, or tissues, or even function, does not accomplish the end in view, namely, simplicity. The difficulty met with is due to the fact that our conception of a gland rests largely with the physiological action of gland cells rather than with any common intrinsic anatomical quality.

Endothelium.—This term, introduced by His in 1865, is generally applied to the layer of cells that line closed cavities, such as peritoneal and pleural cavities, circulatory system, and cavities of joints.

These cells thus form the inner layer of serous membranes, and while structurally they bear a close resemblance to epithelial cells, there is nevertheless an intrinsic difference made apparent by a comparison of pathological growths from these cells called *endothelioma*, and like growths from epithelial cells called *epithelioma*. Endothelioma are usually slower of growth, less malignant when malignancy exists, and have a tendency to form mucoid deposits. Endothelial cells are mononucleated, scaly, or of the pavement variety with wavy borders, and are held together with a cement substance that requires special staining technique to demonstrate. They impart a transparent, smooth, glistening surface to the membrane which they clothe.

Fig. 29.—Epithelium or endothelium from mesentery. Silver nitrate stain.

Peritoneum and Pleura.—These are true serous membranes, the structure of which is described on page 60. Elastic fibers are particularly abundant in the membrana propria, giving strength to both peritoneum and pleura, so that these membranes are readily sewed in surgical cases. Physiologically these membranes are of the greatest importance:

1. It is claimed that the simple pavement epithelial cells of the peritoneum can produce a secretion that clots, and in this manner adhesions are

quickly formed. This is of the greatest importance in preventing the spreading of an infection, as in peritonitis.

2. These cells act as phagocytes and feed upon bacteria in case of an infection. According to one view they can destroy living bacteria. A second theory is that they act as scavengers and remove only dead bacteria.

Stomata and *stigmata* have been frequently described as minute openings in these membranes to facilitate the absorption of fluids. Stomata are said to have guard cells to regulate the size of the opening, and were supposed to be specially abundant in the peritoneal lining of the diaphragm. The existence of stomata has lately been strenuously denied. The rapid absorption of peritoneal fluid is a well-established fact. If stomata are absent the absorption is purely one of osmosis or dialysis. It should be remembered that drainage is along lymphatic channels and therefore from the pelvis toward the thorax.

II. SUPPORTING TISSUE.

The embryonic connective tissue is largely cellular, but in the adult body the intercellular substance greatly predominates and gives the characteristics on which a classification is based. The cell elements are but slightly modified from the embryonic type, but the cell products or intercellular substance become modified to form bone, cartilage, or connective-tissue fibers. The difference here is relatively a dif-

ference in the degree of condensation of the intercellular substance, being either loosely arranged as in reticular connective tissue, or more compact as in tendons, or a greater degree of condensation as in cartilage, bone, and dentine. In all these types the cellular elements are morphologically very similar, which makes it possible for one form to develop into that of another; for instance, bone is produced from cartilage, or from fibrous connective tissues.

The function of supporting tissue is largely a passive one depending on its physical properties, and the amount of nourishment the cellular elements receive is therefore a very variable quantity. Tendons, particularly, have a limited supply, perhaps because the cells form so small a part of these structures. Nutrition is supplied from the lymph which penetrates the ground substance through clefts or minute channels placed in the intercellular material of the more condensed forms. In bone fine canals develop and anastomose to form a canalicular system, while in other forms, as mucous connective tissue and hyaline cartilage, the nourishing lymph seems to pass through the ground substance regardless of lymph channels, as in these cases the latter have not been found.

Blood vessels and capillaries ramify more or less freely through the matrix of supporting tissue, except in case of cartilage, where they are practically absent. Unlike epithelia, nerves may be abundant, but in no case do nerve fibers unite with the cellular elements; however, special sensory nerve endings

are frequently found, particularly in the connective-tissue elements.

Fat in the human body is mostly found stored up in modified connective-tissue cells. This may occur wherever there is connective tissue, and fat cells must therefore be regarded as modified connective-tissue cells. Likewise certain pigment cells and red blood corpuscles belong to this class.

The supporting tissue is derived exclusively from the mesenchyma, a subdivision of the middle germ layer or mesoderm. It is divided into three classes—*connective tissue*, *cartilage*, and *bone*.

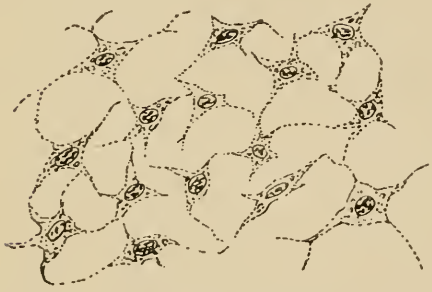


Fig. 30.—Connective-tissue cells from a chick embryo.

Fig. 31.—Connective-tissue cells from Wharton's jelly of the umbilical cord.

1. Connective Tissue.

The elements of this tissue consist of cells and cell products, in the form of connective-tissue fibers, which penetrate and give consistency and support to every organ in the body.

1. **Connective-tissue Cells.**

(*a*) *Embryonic Connective-tissue Cells.*—These are irregular, stellate cells found in embryos and in the umbilical cord. Those of the cord, with the matrix in which they are imbedded, form a soft, pulpy mass

known as *Wharton's jelly*, or *mucous tissue*. These cells are loosely associated in no definite order, their stellate processes interlace and sometimes appear to come in direct contact. Their nuclei are round, or oval, or elongated, forming what is known as the spindle-shaped and pointed nucleus, often resembling the cigar-shaped and rounded nucleus of a plain muscle cell. The nuclei are rich in chromatin, and therefore stain heavily with hematoxylin. Blood- and lymph-vessels mingle freely with these cells; in

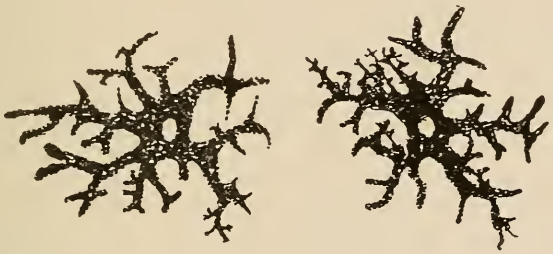


Fig. 32.—Two pigment cells from the dermis of a salamander. The pigment is in the cytoplasm.

fact, this association is constant. The so-called granulation tissue in healing wounds consists of embryonic connective-tissue cells, always bleeds easily, because of its vascularity, and painless because of absence of nerve endings.

(*b*) *Pigment Cells.*—These are connective-tissue cells in which pigment is stored in the cytoplasm, never in the nucleus. The cells are extensively branched, large and flat. In amphibians and reptiles they are abundant in the dermis of the skin, and enable the animal to change its color, as is the case with the tree toad and the chameleon. In the human

body connective-tissue pigment cells are limited to the choroid coat and iris of the eye, to birth-moles, and to the piamater of the brain. The pigment may be of any color, the constituent being *melanin*, a coloring material probably derived from the blood.

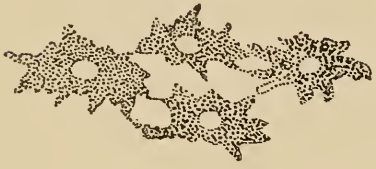


Fig. 33.—Pigment cells from the choroid coat of the eye. These cells are of connective-tissue origin.

(*c*) *Fat Cells.*—These are connective-tissue cells with a large storage of fat. The fat occupies the center of the cell as a big drop which crowds the cytoplasm and nucleus to one side, closely pressed against the cell wall, which is unusually conspicuous. The cells are large and spherical. Since fat is dissolved by alcohol, these cells in sections are distorted, polyhedral, and appear more like irregular spaces than anything else. Normal fat is not to be confounded with pathological fat found in fatty degeneration of organs. In the latter case the fat appears as little droplets diffused through the cytoplasm of the diseased cells, and is produced at the expense of protoplasm, a destructive process or katabolism. Normal fat is a constructive process or anabolism, and is therefore a storage of food or potential energy. Its production, physiologically, is not clearly understood. It may be produced from

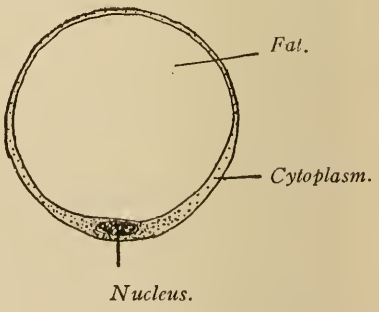


Fig. 34.—Normal fat cell.

a proteid diet, but its production is more easily prompted by a fatty diet and the carbohydrates. Cold prompts its production, as is clearly manifest in hibernating animals when the cold season approaches, and the increased weight of animals, as a rule, during the winter season.

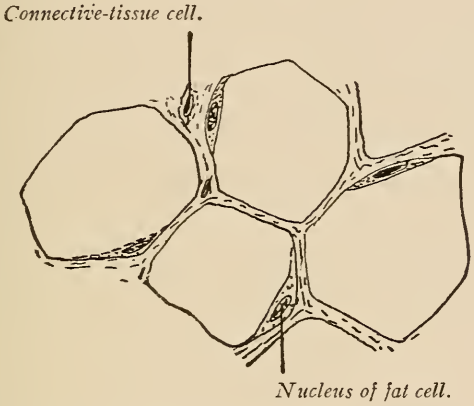


Fig. 35.—Fat cells as they appear in sections treated with alcohol. Alcohol dissolves the fat.

The usual stain for fat is osmic acid, in which fat acts as a reducing agent, precipitating black osmium. Any reducing agent will do this, as is made evident by the black color of the cork in a bottle containing osmic acid solution, fat being absent from cork.

Other connective-tissue cells, as *Plasma cells*, *Wandering cells*, and *Mast cells*, are frequently described. These resemble normal constituents of blood and lymph to which they may belong.

2. **Connective-tissue Products.** — These products may be a jelly-like substance or fibers. Connective-tissue cells are always associated with these products. There are two theories as to the production of fibers.

(*a*) The fibers may be processes of the cytoplasm that lose their cell connection.

(*b*) The connective-tissue cells may secrete a homogeneous matrix, which later becomes striated, producing fibers in a manner as fibrin is formed in clotting blood.

Fig. 36. — Reticular tissue from a lymph gland.

Connective tissue is classified according to its matrix into:

1. *Mucous Connective Tissue.* —This consists largely of embryonic connective-tissue cells and a jelly-like matrix or ground substance which gives a reaction for mucus. It is found in the umbilical cord, where it is known as Wharton's jelly, and in embryonic tissue.

2. *White Fibrous Connective Tissue.*—This consists largely of white nonelastic fibers. The fibers are parallel to each other, not branched, and yield gela-

Fig. 37.—Teased tendon, showing fine wavy white fibers.

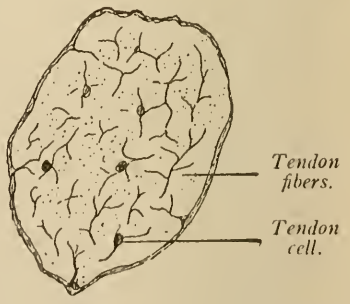


Fig. 38.—Cross section of tendon.

tin on boiling. The fibers swell up when treated with acetic acid. They are found in tendons, the aponeuroses, and ligaments, the fascia of muscles, the dura mater, and the fibrous capsules of many organs.

3. *Yellow Fibrous Connective Tissue.*—The matrix in this consists of elastic fibers that are branched, and usually coarser than the white nonelastic fibers. They do not swell up when treated with acetic acid and yield elastin on boiling. Like the preceding, the fibers are frequently grouped into bundles with a limited supply of blood-vessels and connective-tissue cells. This tissue is found wherever elasticity is required, as in the ligamentum nuchæ and subflava, in the walls of

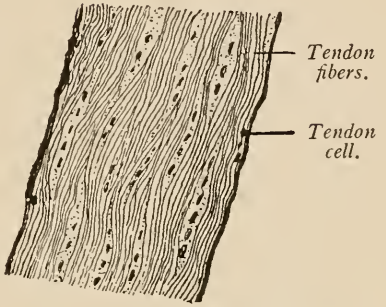


Fig. 39.—Longitudinal section of tendon.

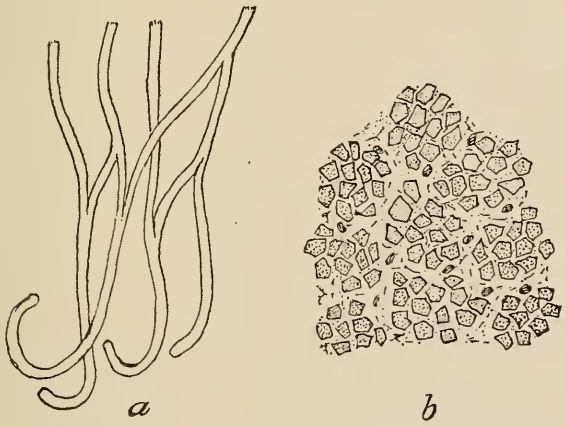


Fig. 40.—*a*, Yellow elastic fibers from the teased ligamentum nuchæ of the ox; *b*, Cross-section of a portion of the ligamentum nuchæ of the ox. The elastic fibers are grouped in bundles with a few intervening connective-tissue cells.

arteries, and in the membrana propria of the peritoneum and pleura.

4. *Reticular Connective Tissue.*—This is a reticu-

lum of interlacing fibrils and is found in adenoid tissue, lymph nodes, spleen, and membrana propria of mucous membranes. Also, to a limited extent, in bone marrow.

5. *Areolar Connective Tissue.*—This is really a mixture of interlacing bundles of white and yellow elastic fibers. It is found subcutaneously to the skin, to which it imparts elasticity. Areolar tissue is vascular and favors, therefore, a rapid spread of bacteria. Over bony prominences there is a limited supply of areolar tissue and the skin at these places has restricted mobility. It is at these points that the spread of an infection, such as erysipelas, is checked.

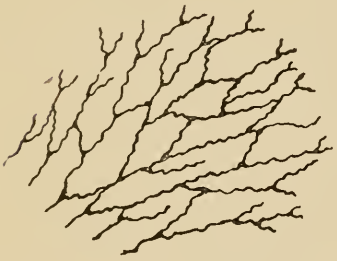


Fig. 41.—Elastic fibers of the mesentery.

General Considerations.—On account of the embryonic condition of connective-tissue cells these, like epithelial cells, are frequently met with in pathological tumors. If the tumor is malignant it is called a *sarcoma*, and is as fatal to life as carcinoma, or cancer. If the tumor is made up largely of fat cells, it is called a *lipoma*, and if the fibrous elements predominate it is a *fibroma*.

The production of connective tissue is often nature's method of checking the spread of a disease. This tissue is produced as a wall in advance of a spreading infection, and if the bacteria are unable to penetrate this barrier, the disease soon becomes self-limiting. This accounts for the swollen infected

parts, and also for the redness, which is due to the extensive blood supply which is always associated with this tissue. Such a swollen tumor represents an *induration* and a *congestion*. In this manner a whole or a part of an organ may be affected. The connective-tissue fibers are absorbed with difficulty or not at all, and a permanent mark or scar remains as an evidence of the injury. In a healing wound, particularly if infected, these fibers are abundantly produced, and its redness is evidence of its extensive vascularity or blood supply. Later, these fibers contract, which occludes the blood, and then the color changes from a red to a white scar that no medical treatment can remove.

Pigmentation is a most important subject. Pigment appears, as a rule, in the cytoplasm of cells, seldom between the cells. It is not confined to connective-tissue cells, but is common to epithelial cells, as the deep layer of the epidermis giving the color of races; is found in the retina cells, where it is always black, and in hair and nails. It appears in the cytoplasm of muscle cells, particularly in old heart muscle,where it is found near the ends of the nuclei, and is nearly always present in nerve cells, giving a gray color to this tissue. Pigmentation is an accompaniment of many diseases, particularly skin diseases. It is also produced under the influence of light, as freckles, that can only be removed by the normal exfoliation of the epithelium.

The production of pigment seems to depend upon the blood. As blood is absent from epithelium there are two theories as to the manner in which the cells obtain it: (*a*) they may receive it directly from the

blood, or (*b*) connective-tissue cells may elaborate it and deliver it secondarily to the epithelial cells. That the pigment is not intrinsic to epithelial cells is proved by the fact that colored skin grafted on a white man soon turns white, and white skin grafted on a colored person turns black. The fruitless attempts to change one's color are well known.

A *melanotic sarcoma* is a pigmented connective-tissue tumor, very malignant, whose cells disseminate very rapidly throughout the body, producing everywhere new tumors. These cells have their origin from normal pigmented connective-tissue cells, and therefore are supposed to come from birth-marks, or the choroid of the eye, or the piamater of the brain. The etiology of such tumors is unknown. Fortunately they are rare.

The facts to be remembered in regard to connective tissues are: 1. The easily stained round, or oval, or spindle-shaped nucleus. 2. The cells are loosely thrown together, not in compact layers or strata. 3. The stellate cells, although the processes are often inconspicuous and not readily detected. 4. The tissue is vascular where cells are abundant. 5. The absence of free nerve endings as among epithelial cells. 6. They do not secrete as do the epithelial cells.

2. Cartilage.

Cartilage is supporting tissue in which the intercellular substance predominates and yields *chondrin* upon boiling. The cartilage cells are typical connective-tissue cells, and occupy lenticular spaces in the matrix called *lacunæ*. Cartilage is surrounded by a dense connective-tissue membrane called the

perichondrium, in which smaller blood-vessels ramify. Blood- and lymph-vessels are absent from the cartilage matrix, except rarely and in places where active growth or ossification is going on they may be present. According to the structure of the matrix, cartilage is classified as,—

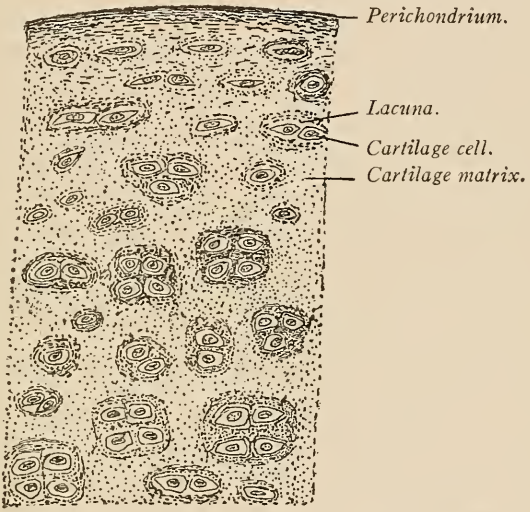


Fig. 42.—Section of hyaline cartilage from the trachea.

1. **Hyaline Cartilage.**—This is the simplest and most common form of cartilage. The matrix appears

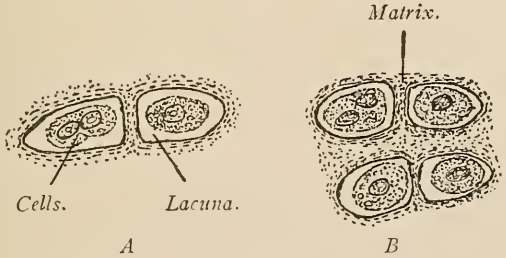


Fig. 43.—Two groups of cells from hyaline cartilage: *A*, Two cells found just beneath the perichondrium; *B*, Four cells found deeper in the cartilage matrix.

to be a homogeneous substance, although many fine interlacing fibrils are present. The lacunæ near the perichondrium have their long axis parallel to the

surface, while deeper in the matrix the long axis is often at right angles to the surface. Each lacuna contains one or more cartilage cells. The cartilage surrounding lacunæ usually stains differently from the balance of the matrix.

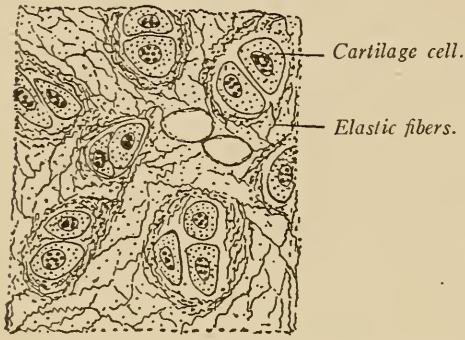


Fig. 44.—Section of elastic cartilage from epiglottis.

This cartilage occurs as articular cartilage of joints, at the end of ribs, and in the nose, the larynx, the trachea, and bronchi.

2. **Elastic Cartilage.**—Elastic cartilage differs from the hyaline variety in having typical interlacing, branched elastic fibers that form a dense network. This cartilage is found wherever elasticity is required, as in the external ear, the Eustachian tube, epiglottis, part of arytenoid cartilages, and cartilages of Wrisberg and Santorini.

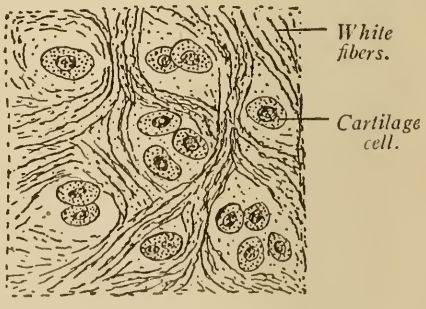


Fig. 45.—Section of white fibrocartilage from symphysis pubis.

3. **White Fibrous Cartilage.**—In this variety the white fibers predominate. As a rule these fibers run parallel in bundles and do not branch. A granular matrix intervenes between the fibers. Fibrous cartilage is found in the intervertebral disc, in the sym-

physis pubis, and in the insertion of the round ligament.

General Considerations.—Cartilage tumors are known as chondroma, and are common. Like cartilage they are of slow growth and therefore harmless. The absence of blood accounts, in large part for the inactivity of the cartilage cells, both in the normal and pathological condition. Furthermore, cartilage cells are enclosed in the matrix in a manner that inhibit their multiplication. Cartilage therefore grows by apposition or acquisition, not by intussusception, like most tissues.

Cartilage slowly ossifies with age. During this process loops of blood-vessels enter the matrix from the perichondrium, and lime salts are deposited adjacent to the cartilage cells. This process will be further described under bone development.

The identification of cartilage is very easy, as the matrix has a marked affinity for many stains.

3. Bone.

Bone is the chief supporting tissue of the body, and consists of a calcified intercellular substance, mostly calcium phosphate, and connective-tissue cells, or bone cells. Organic substance constitutes one-third the weight, and inorganic substance two-thirds the weight of bone. The bone cells, sometimes called bone corpuscles, are flattened stellate cells with many slender processes, and a well defined round or oval nucleus. Like cartilage cells they lie imbedded in lenticular spaces called *lacunæ*. These lacunæ, however, communicate with adjacent lacunæ by means of numerous capillary tubes called

canaliculi, into which extend the slender cell processes. Through these canaliculi the imprisoned cells receive their nourishment and give up their waste products.

Haversian System.—This consists of a Haversian

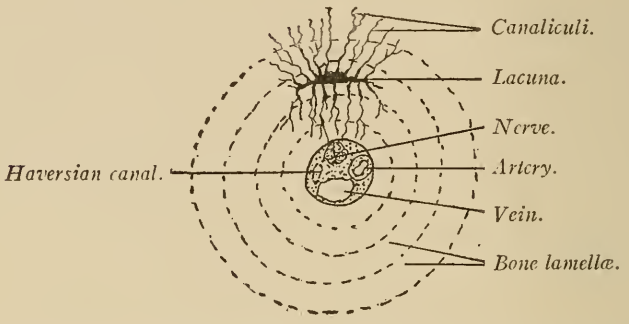


Fig. 46.—Haversian system with only one lacuna sketched.

canal, containing an artery, vein, and nerve, bone lamallæ concentrically arranged around the canal, and from two to six rows of concentrically arranged cells with their lacunæ and canaliculi. The canals average 0.05 mm. ($\frac{1}{500}$ inch) in diameter. The canals, as a rule, run parallel with the shaft of the bone, but communicate freely with each other. The blood penetrates as far as the Haversian canals but the lymph reaches each bone cell through the finer canaliculi. The nerve terminates in the wall of the blood-vessels and has no connection with the bone cells.

Fig. 47.—Bone cell or corpuscle. The cell occupies a lacuna.

Haversian systems occupy a central zone in a bony shaft. External and internal to this zone compact lamellæ are present, arranged parallel to the surface.

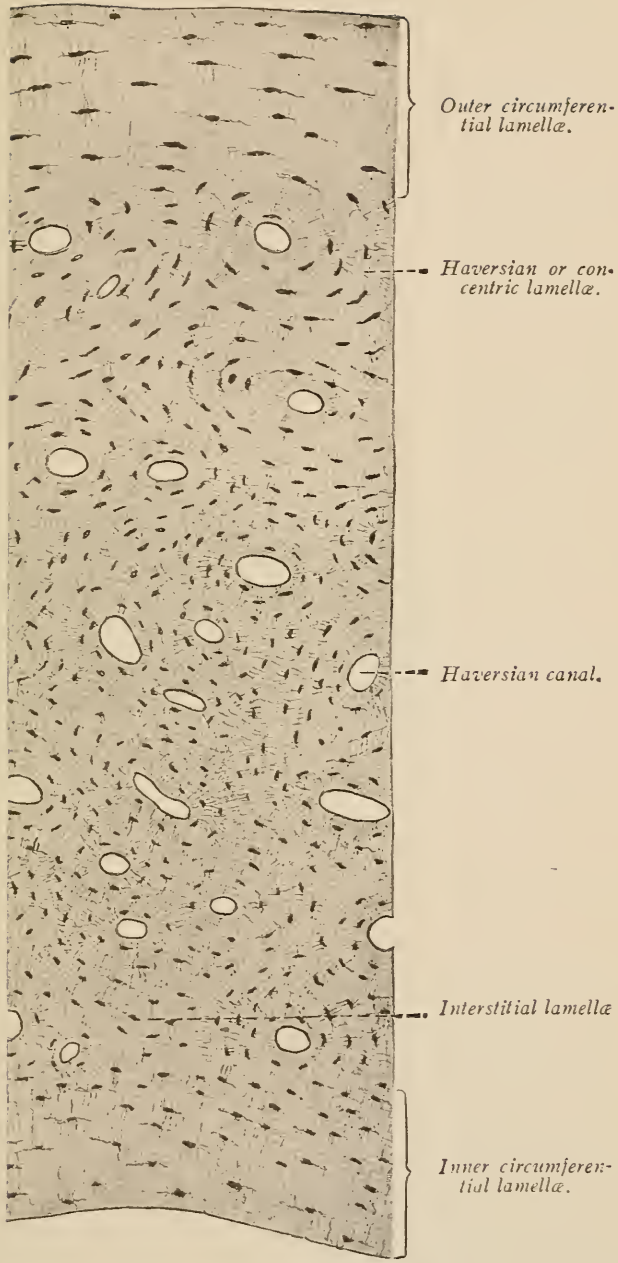


Fig. 48.—Segment of a transversely ground section from the shaft of a long bone, showing all the lamellar systems. Metacarpus of man (Böhm and Davidoff).

In the circumferential lamellæ canals, called *Volkmann's canals*, convey blood-vessels to the Haversian canals. In the angular interstices, between the Haversian systems, lamellæ and canaliculi are found arranged like those of the circumferential lamellæ. The shafts of long bones contain a marrow cavity. At the ends the marrow cavity disappears, and the bony structure becomes spongy with many interstices and is then called *cancellate bone*. The middle of flat bones is made up of a like loose structure called *diploe*.

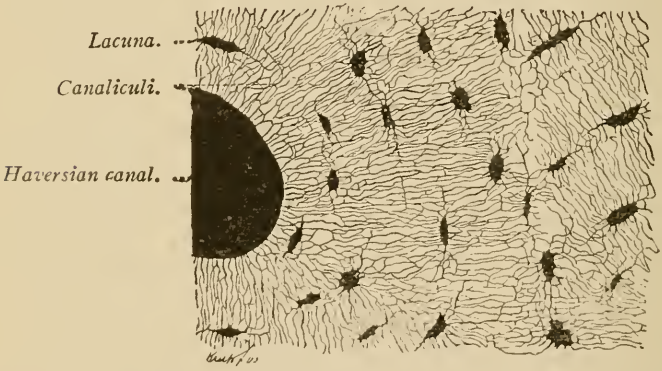


Fig. 49.—Portion of a transversely ground disc from the shaft of a human femur (Böhm and Davidoff).

Periosteum.—The periosteum is a dense, fibrous, connective-tissue membrane that covers the bone and is derived from the perichondrium of the cartilage. It is composed of two layers, (*a*) an inner layer that contains many elastic fibers and osteoblasts, or bone-forming cells, known as the *osteogenetic layer*, and (*b*) an outer layer of coarse, white, fibrous bundles where numerous blood-vessels ramify and send branches to the Haversian canals.

The periosteum is anchored to the compact bone by means of bundles of fibers (*Sharpey's fibers*) that pass concentrically or parallel to the Haversian systems.

Blood Supply.—The compact bone is supplied with blood from the periosteum. Larger blood-vessels, called *perforating vessels*, pass directly through the bony shaft and supply the marrow. In removing bone, as a rib, the periosteum is not taken away, and because of the latter's vascularity and osteogenetic layer, the removed part regenerates. On the other hand, infected marrow and diseased bone may be removed from the inner surface until a mere shell remains of the once solid shaft. If all the infection is removed a regeneration follows.

Development of Bone.—The development of bone is either *intramembranous* or *endochondral*. In the latter a cartilage stage intervenes, otherwise the history in each case is the same. A synopsis of endochondral development is as follows:

1. A solid shaft of hyaline cartilage, non-vascular and without any marrow cavity.

2. In the center of this shaft the cartilage cells enlarge, their lacunæ enlarge and coalesce, particularly along lines extending toward the ends of the bone. The rosette produced by this excavation is called the *primary areola of Sharpey*.

3. Lime salts are deposited in the thin walls of these spaces, making calcified cartilage.

4. Osteogenetic cells and blood-vessels from the periosteum enter the cartilage spaces. The cartilage cells *disappear* with this invasion and the ex-

cavation, begun by the cartilage cells, is further enlarged by the bone cells. The excavated areas are now called the *secondary areolæ of Sharpey*, the cavities having a rich blood supply quite in contrast with the primary areolæ. The marrow cavity

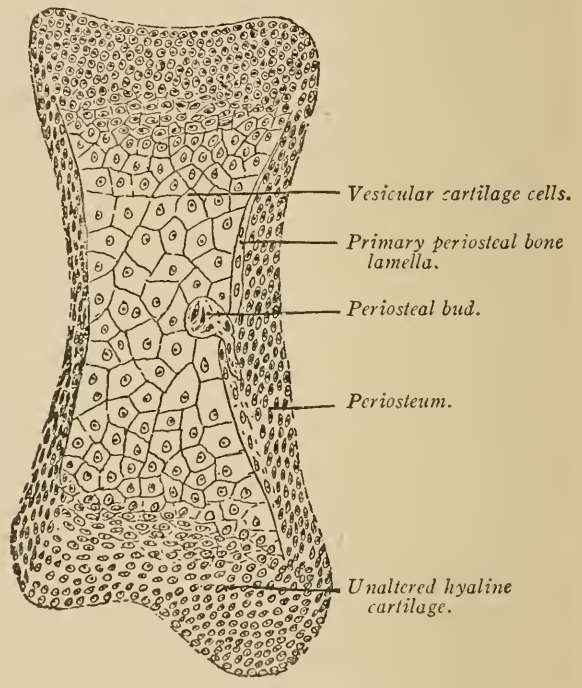


Fig. 50.—Longitudinal section through a long bone (phalanx) of a lizard embryo. The primary bone lamella originating from the periosteum is broken through by the periosteal bud. Connected with the bud is a periosteal blood-vessel containing red blood-corpuscles (Böhm and Davidoff).

is excavated and the shaft becomes longitudinally porous. Endochondral bone, therefore, develops *in* cartilage, not *from* cartilage.

5. Osteogenetic cells attach themselves to the wall of these enlarged Haversian canals and become enclosed in lime deposits, forming thus the outer lamellæ and outer row of bone cells of each Haversian

system. Cells with lamellæ are added centripetally to this outer row and thus ultimately complete the Haversian system, leaving a small central canal containing vessels and a nerve.

Ossification begins in the center of the cartilage shaft and proceeds gradually toward each end, so that all the above changes occur at one and the same time. After birth these changes go on at the ends of the bone, so long as it keeps growing. During this period the bone is made thicker by deposits from the periosteum forming the circumferential lamellæ of bony shafts. These lamellæ are added without the intervention of a cartilage stage and therefore represent intramembranous development.

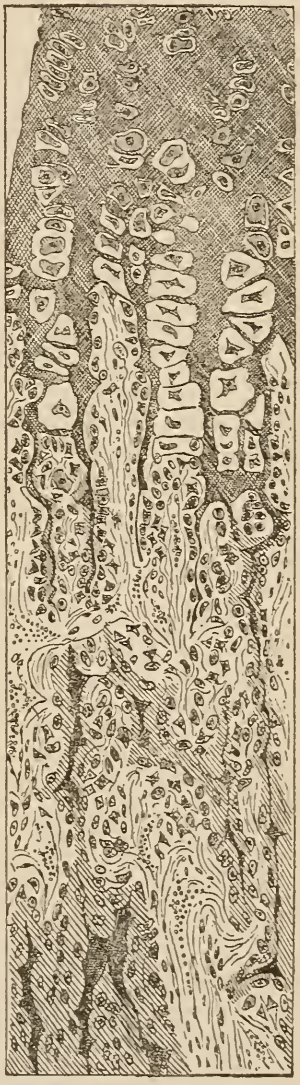


Fig. 51.—Longitudinal section through area of ossification from long bone of human embryo (Huber).

Regeneration of Bone.—The embryonic process of developing bone is repeated every time a broken bone heals. As a rule the cartilage stage does not intervene. A synopsis of the healing process of a simple fracture is as follows:

1. Hemorrhage and clot. The fibrin of the clot tends to hold the broken ends in apposition. The parts are swollen and red, due to the influx of blood.

2. Organization of the clot. Connective-tissue cells and white corpuscles enter the clot, feed upon it and ultimately replace it, the connective-tissue cells meanwhile producing fibers. The organized clot is a more substantial fabric and more firmly holds the broken ends in apposition.

3. Osteogenetic cells enter the organized clot and deposit lime salts, producing a primary callus. The connective fibers shrink, pulling the broken ends firmly together, producing a sensation known as knitting of bone. The primary callus surrounds the bone, and may even fill the marrow cavity.

4. Haversian systems are formed, uniting the broken ends. These systems appear just as described under development of bone.

5. Primary callus is absorbed and marrow cavity excavated. Bone cells called *osteoclasts* are supposed to be active factors in this absorption.

General Considerations.—Bone does not grow in the same sense as other tissues do. Any increase in size is due to apposition of bone lamellæ upon those already formed. Accompanying and often preceding bone production we usually find a destructive or excavating process. It is believed two classes of cells bring about these changes: (*a*) *Osteoclasts* that cause bone absorption, and (*b*) *osteoblasts* that engage in bone production. The latter are supposed to be particularly abundant in the osteogenetic layer of the periosteum.

Bone tumors are not uncommon and are called *osteoma*. They are of slow growth, usually associated with bone, and harmless.

On account of the great vascularity, a broken bone heals more rapidly than a broken tendon, or ligament, or a broken cartilage. An old bone is brittle and the healing process a slow one on account of the increase of earthy matter and a decrease of the organic.

An infection beneath the periosteum is a *felon*. The periosteum is firmly attached to the bone by Sharpey's fibers and the pressure produced by an infection beneath it gives rise to extreme pain, which is instantly relieved by an incision. An inflammation in the bone is called an *ostitis*, while if it is located in the marrow cavity it is called an *osteomyelitis*.

III. MUSCULAR TISSUE.

Muscular tissue consists of elongated cellular elements in which contraction takes place along the long axis of the cell. This contraction is intrinsic to the muscle cytoplasm, and of this the spongioplasm seems to be the active agent. The word *sarcode* and its derivatives is used in describing muscle protoplasm. This word was introduced by Dujardin, in 1835, and was later replaced by the word *protoplasm*.

1. **Smooth, Non-striated or Involuntary Muscle.**—This is the simplest form of muscle tissue. The cells are mononucleated, elongated, or spindle-shaped, and vary in length from 40 to 200 μ. The nucleus occupies the center of the cell, is rich in chromatin, and oval, with blunt ends, or cigar-shaped. The

cytoplasm is longitudinally striated, the striations being due to fibrils or *sarcostyles*, which are, structurally, probably analogous to the spongioplasm. Between the fibrils there is a homogeneous substance, the sarcoplasm, which is analogous to the hyaloplasm. These cells are enclosed in a delicate cement layer usually not described as a cell wall, and in which a fine interlacing reticulum has recently been described. The ends overlap each other and are held together by a delicate cement substance. Nerve-fibers from the sympathetic nervous system reach the muscle cells and terminate in small granules upon the muscle cytoplasm.

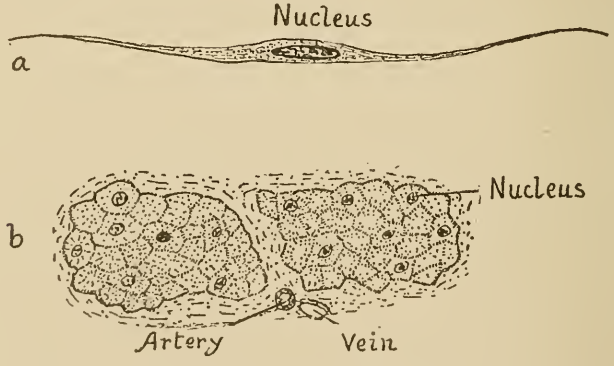


Fig. 52.—*a*, Cell from smooth muscle of intestine; *b*, Cross section of smooth muscle of intestine.

Smooth muscle is found in the wall of the tubes of the body, and invariably in thin layers, with one exception—the wall of the uterus—where the muscle may be an inch in thickness. Usually, too, this muscle is laid down as an internal circular layer with an externally applied and thinner longitudinal layer. Plain muscle is found in the wall of the alimentary tract, trachea and bronchi, bladder, ureter, uterus, Fallopian tubes, urethra, vas deferens,

blood-vessels, lymph-vessels, large ducts of glands, nipple, hair-follicles, Eustachian tube, spleen, prostate gland, ciliary muscles, and iris of the eye.

2. **Cardiac Muscle.**—The heart ontogenetically is a modified blood-vessel, and its muscle, therefore, has the same origin as smooth muscle. Heart-muscle cells are oval or brick-shaped and mononucleated, the oval nuclei occupying the center of

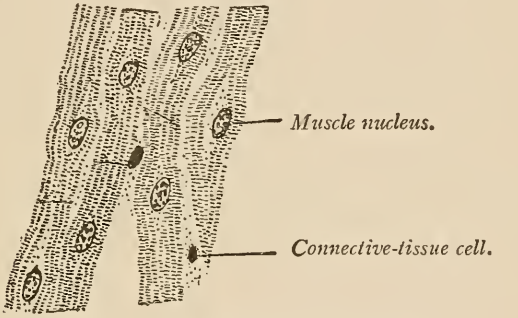


Fig. 53.—Longitudinal section of heart muscle fibers.

the cell. Longitudinal fibrils and, in addition, a fine cross striation, are present in the cytoplasm, resembling the cross striation of voluntary muscle. This cross striation is explained under Voluntary Muscle, and therefore will not be given here. The cells are joined together, end to end, by delicate cement lines and laterally may unite with adjacent cells by means of protoplasmic processes. In the cytoplasm adjacent to the ends of the nuclei, normally fat is frequently present and

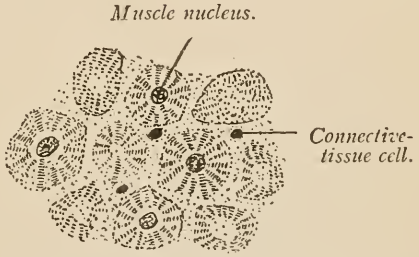


Fig. 54.—Cross section of heart muscle fibers.

also some pigment. The latter is more prominent in old hearts, to which it imparts a brown color.

At present the exact structure of the heart muscle is a disputed question. In sections, many breaks or artifacts resemble the cement lines separating adjacent cells. The longitudinal fibrils are said to penetrate the cement and thus establish a continuity of protoplasm between adjacent cells. The presence or absence of a cell wall, analogous to the sarcolemma of voluntary muscle, is also disputed.

3. **Voluntary Muscle.**—A voluntary muscle fiber is a multinucleated, greatly elongated cell, which may attain a length of 12 cm. (5 inches). These fibers are arranged parallel to each other and grouped into bundles, called *fasciculi*. Each fasciculus is

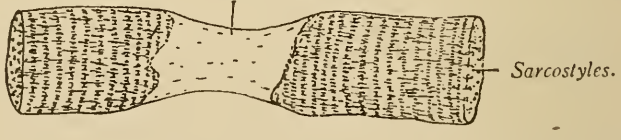


Fig. 55.—Voluntary muscle fiber. The sarcoplasm has broken, showing the smooth sarcolemma.

surrounded by connective-tissue cells and fibers in which many blood-vessels ramify. A finer fabric of connective tissue penetrates the fasciculus and gives support to the individual fibers. The connective tissue that enters a fasciculus is called the *endomysium*, and that which surrounds a fasciculus is called the *perimysium*. Fasciculi are grouped into coarser bundles and these collectively make up a muscle. The muscle is in turn enveloped in a firm connective-tissue layer called the *epimysium*. In gross anatomy the latter constitutes the deep fascia

of muscle. In tough meat the connective-tissue element is extensively developed and the fasciculi are large and coarse.

Each muscle fiber has a delicate, transparent, smooth cell wall called the *sarcolemma*. The oval distinct nuclei lie immediately beneath the sarcolemma in higher vertebrates, but in lower forms and in all embryos the nuclei lie deeper in the muscle protoplasm. These nuclei have the same structure as the nuclei of any other tissue, but the cytoplasm shows a distinct and regular cross and longitudinal striation, characteristic of only one other tissue—the cardiac muscle. The longitudinal striation is due to the presence of delicate fibrillæ called *sarcostyles*, which is analogous to the spongioplasm of other cells. A more homogeneous and fluid substance intervenes between the sarcostyles, called *sarcoplasm*, and is in turn analogous to the hyaloplasm of other cells. The sarcostyles are not uniformly or evenly distributed in each muscle fiber, but are grouped into bundles. In cross sections the fiber has therefore a honeycomb structure, the minute areas being known as *Cohnheim's fields*. A single Cohnheim field represents the cut ends of a single bundle of fibrils or sarcostyles.

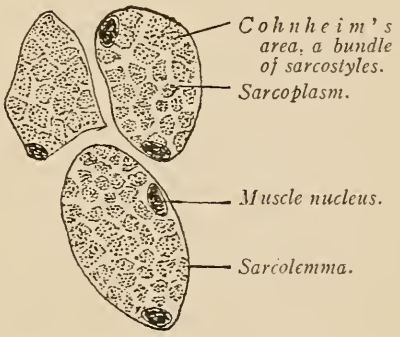


Fig. 56.—Cross section of three voluntary muscle fibers.

The cross striation is intricate and therefore more difficult to explain. This striation consists of alter-

nating light and dark bands. The dark bands are doubly refractive to light, or *anisotropic*, while the light bands are singly refractive, or *isotropic*. The dark bands represent a predominance of the sarcostyle substance, and the light bands a predominance of the sarcoplasm. In the middle of the light band a dark line can be seen, known as *Krause's membrane*. In the middle of the dark band a light-colored line is present, known as *Hensen's median disc*. The latter disappears when a fiber contracts.

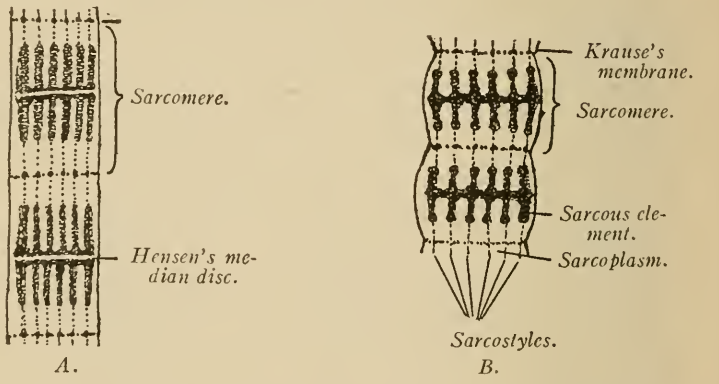


Fig. 57.—Diagram of voluntary muscle fiber; *A*, Fiber relaxed; *B*, fiber contracted.

These transverse markings are all due to the distribution of the sarcoplasm and the regular constrictions of the sarcostyles. The sarcostyles are not of uniform dimensions, but at regular intervals show dilatations alternating with constrictions. The dilatations appear at regular intervals and in the same transverse plane of the muscle fiber, thus giving rise to the dark band. Krause's membrane is not a membrane, but represents minute nodal points of the sarcostyles, placed in the same trans-

verse plane of the fiber and in the middle of the light band. The light band represents an abundance of sarcoplasm and it is in this sectional area that the sarcostyles suffer a constriction. As Hensen's median disc is a light line in the middle of the dark band there must be a deep constriction, if not a complete constriction of the sarcostyles at this point.

The whole muscle fiber between the two Krause's membranes is called a *sarcomere*, and consists of a median dark band and the proximal halves of the adjacent light bands. A single fibril or sarcostyle between two of Krause's membranes is called a *sarcous element*.

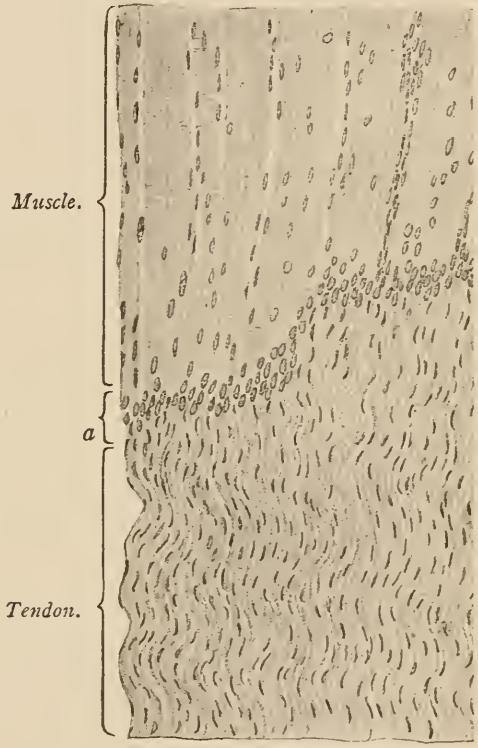


Fig. 58.—Part of a longitudinal section through the line of junction between muscle and tendon. At the line where the tendon fibrils join the sarcolemma (*a*), the nuclei of the muscle are very numerous. Sublimate preparation (Böhm and Davidoff).

It is believed that muscular contractility is particularly a function of the sarcostyles and that the sarcoplasm serves more as a storage of energy or food. As to color there are two kinds of muscle, white and red. In white meat, as the muscle of the

breast of a bird, the fibers have a poor supply of sarcoplasm and a predominance of sarcostyles. In red meat the fibers are rich in sarcoplasm and have a less supply of the sarcostyle protoplasm. In the myology of man both kinds of fibers are present. The white fibers are more powerful but have less endurance; that is, if held in tetanic contraction with no interval of rest they would tire quicker than the red fibers. The pectoral muscle of birds is powerful, but would soon tire but for the interval of rest that intervenes between the strokes of the wing; that is, during its upward movement.

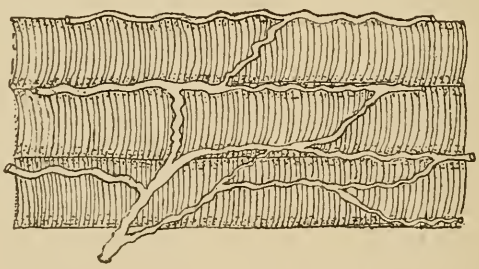


Fig. 59.—Three voluntary muscle fibers from an injected muscle, showing network of blood-capillaries.

Blood Supply.—Blood-vessels follow the connective tissue of a muscle, and penetrate to the individual fibers where they break up into capillaries. These vessels run, as a rule, parallel to the fibers, forming a network with anastomosing branches. They extend in a varicose manner between the fibers in such a way that when a muscle contracts they readily adjust themselves, without breaking.

Nerve Supply.—Medullated nerve fibers accompany

the blood-vessels and terminate beneath the sarcolemma in special end plates called *muscle plates*. These will be described under *special nerve endings*. Non-medullated or sympathetic nerve fibers also accompany blood-vessels, but they innervate the involuntary musculature of arteries and veins.

Distribution.—Voluntary muscles are the skeletal muscles, and make up the bulk of the body. Striated fibers are present in the upper part of the esophagus, and also constitute the platysma muscle of the skin.

Union with Tendon and Bone.—The muscle fibers terminate abruptly with tendon fibers. This is not a direct end-to-end union, but the tendon fibers fuse with the sarcolemma at an angle. In the same way the muscle fibers unite with the periosteum of the bone. At this point Sharpey's fibers are particularly abundant and firmly anchor the periosteum to the compact bone lamellæ.

General Considerations.—A muscle tumor is called a *myoma*. Tumors of plain muscle are common in the wall of the uterus. They are benign, of slow growth, and usually harmless. A tumor of striated muscle fibers is very rare. The tissue is highly specialized and the fibers therefore do not multiply readily. If a muscle is injured or cut the voluntary fibers regenerate partly from the cut end and partly from free muscle nuclei that are shed into the wound, but mostly by connective-tissue repair that leaves a permanent scar.

The physiological action of plain muscle is slow, producing peristaltic contractions. That of voluntary muscle is rapid, as in the wings of insects.

Voluntary muscles, while more powerful, tire easily. Plain muscle has a wonderful endurance. The pain produced by violent action of plain muscle is in direct proportion to the degree of contraction. Some examples are: the colicky pains of the intestine; labor pains; pains due to calculi in the ureter or bile duct; or the pain in appendicitis produced by contraction of the plain muscle of the appendix. These pains have many things in common They may last for hours, they remit and recur with regularity, and they come in waves.

An infection in a muscle, as a psoas abscess, bur-

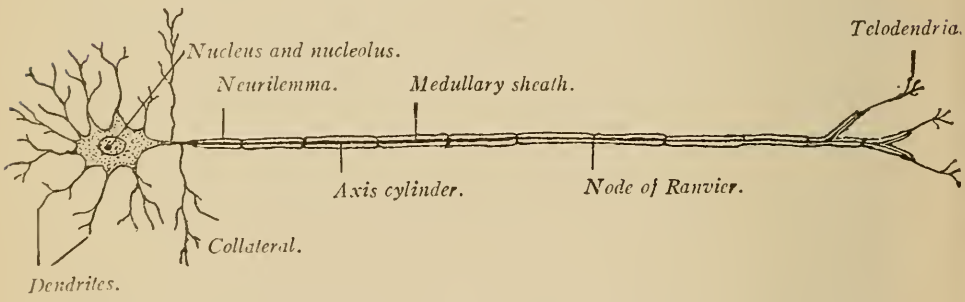


Fig. 60.—Diagram of a neuron.

rows in the fascia,—that is, spreads along the connective-tissue septa, perimysium and endomysium. The quality of meat depends on the amount of connective tissue. In tough meat the fasciculi are coarse and perimysium abundant. In tender sirloin the reverse prevails.

IV. NERVOUS TISSUE.

Nervous tissue is most highly specialized of all tissues and consists of elements called *neurons*. A neuron is a nerve cell with all its processes. These cells vary greatly in size; usually they are large.

They have one or more processes, no cell wall, and a distinct nucleus. The nucleus has a conspicuous nucleolus, a prominent nuclear membrane, but a small supply of chromatin.

The cytoplasm is usually pigmented, the pigment being collected to one side of the cell. It is this pigment that gives nervous tissue a gray color wherever these cells are found. Fat and vacuoles are also usually found in the cytoplasm. The processes of nerve cells are:

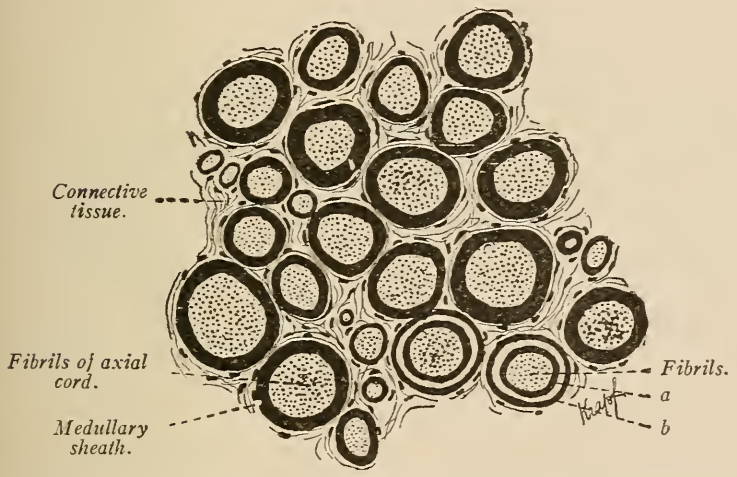


Fig. 61.—Transverse section through the sciatic nerve of a frog. At *a* and *b* is a diagonal fissure between two Lantermann's segments; as a result, the medullary sheath here appears double (Böhm and Davidoff).

1. *Axis cylinder* (Deiters' process, axon, neurite, or neuraxon), which is usually a long protoplasmic process that physiologically carries an impulse away from the cell. *Collaterals* are nerve processes that leave the axis cylinder at right angles. They are commonly found near the nerve cells, but may appear at a node of Ranvier some distance away from the nerve cell.

2. *Dendrites*, which are usually short processes, very much branched, and physiologically carry an impulse toward the nerve cell. A collection of nerve cells constitutes a *ganglion*, while a *nerve plexus* is a reticulum or interlacing of nerve fibers. Nerve cells are classified, according to the number of their processes, into *unipolar*, *bipolar*, and *multipolar*.

Nerve Cells.—1. *Unipolar nerve cells.*—These are nerve cells with but one process. If a nerve cell

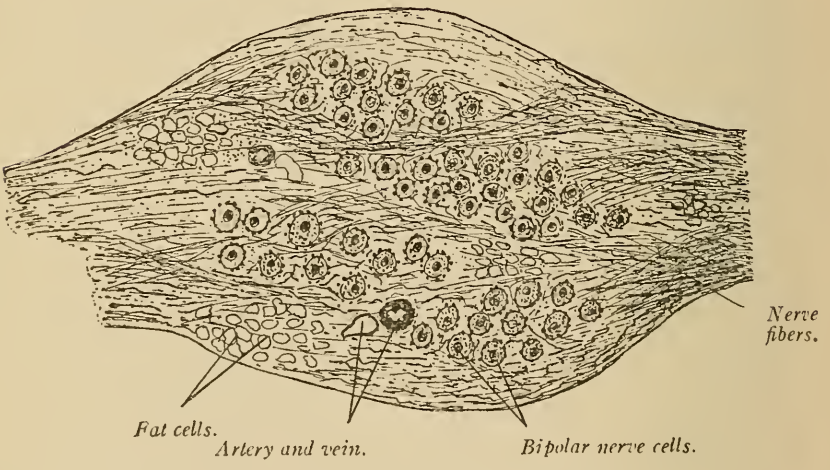


Fig. 62.—Section of spinal ganglion.

has but one process that process must be an axis cylinder. If a nerve cell has many processes only one is an axis cylinder, the others are dendrites. Unipolar nerve cells are found in the olfactory mucous membrane. They are columnar or cylindrical and each gives rise to a basal process, the axis cylinder, which remains non-medullated and extends through the cribriform plate to enter the olfactory lobe of the cerebrum. This class of nerve cells is common in invertebrates.

2. *Bipolar Nerve Cells.*—Bipolar nerve cells have two processes,—one axis cylinder and one dendrite. Nerve cells of the spinal ganglia and ganglia of the

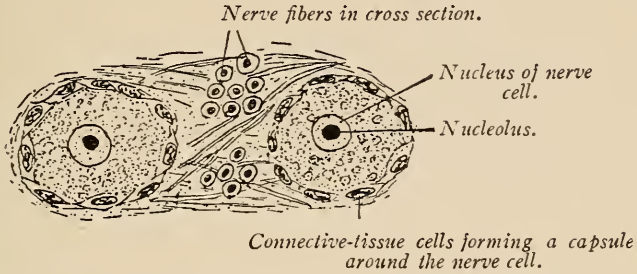

Nerve fibers in cross section.
Nucleus of nerve cell.
Nucleolus.
Connective-tissue cells forming a capsule around the nerve cell.

Fig. 63.—Two bipolar nerve cells from the spinal ganglion.

cranial nerves belong to this class. These cells apparently are unipolar, but their embryology clearly shows the single process to be morphologically equivalent to two. In this particular case the long peripheral process carries an impulse to the cell, and this long process is therefore a dendrite. The short process that unites the ganglion with the central nervous system is the axis cylinder. These large bipolar cells are surrounded by a capsule of connective-tissue cells. The cells are large and the single compound process very soon divides into the two processes mentioned above. The cytoplasm

Fig. 64.—Three ganglion cells from a spinal ganglion of a rabbit embryo. The cells are still bipolar. Their processes come together in later stages, and finally form the T-shaped structure seen in the adult animal; chrome-silver method (Böhm and Davidoff).

of these cells has a fibrillar structure, this striation having a close relation to the fibrillæ of the axis cylinder.

The spinal ganglia are situated on the posterior or sensory root of the spinal nerves and within the vertebral canal. The Gasserian, geniculate, auditory, jugular, and petrosal ganglia of the cranial nerves are morphologically equivalent structures. The nerve cells of all these ganglia are bipolar, with the exception of a few cells said to be multipolar. In addition to nerve cells, nerve fibers and connective-tissue elements make up the histology of these ganglia. A liberal blood and lymph supply is always present.

Fig. 65.—Ganglion cell with a process dividing at *a* (T-shaped process); from a spinal ganglion of the frog (Böhm and Davidoff).

3. *Multipolar Nerve Cells.*—These are nerve cells with many processes, only one of which is an axis cylinder. They constitute by far the bulk of nerve cells and are found in the brain and spinal cord and in ganglia along the sympathetic nervous system. The cells vary in size from 4 μ in the granular layer of the cerebellum to 150 μ, the largest nerve cells of the spinal cord. Chromatophile granules, vacuoles, fat, and a fibrillar structure is found associated with the cytoplasm. Large multipolar nerve cells, called *cells of Purkinje*, are found in the cerebellum and will be described with the histology of that organ.

Nerve Fibers.—1. *Medullated Fibers.*—Medullated nerve fibers usually consist of three parts, (*a*) axis cylinder, (*b*) medullary sheath, (*c*) neurilemma. An axis cylinder is a cell process that carries an impulse away from the nerve cell. It is a slender cytoplasmic process and may be very long, as is the case with

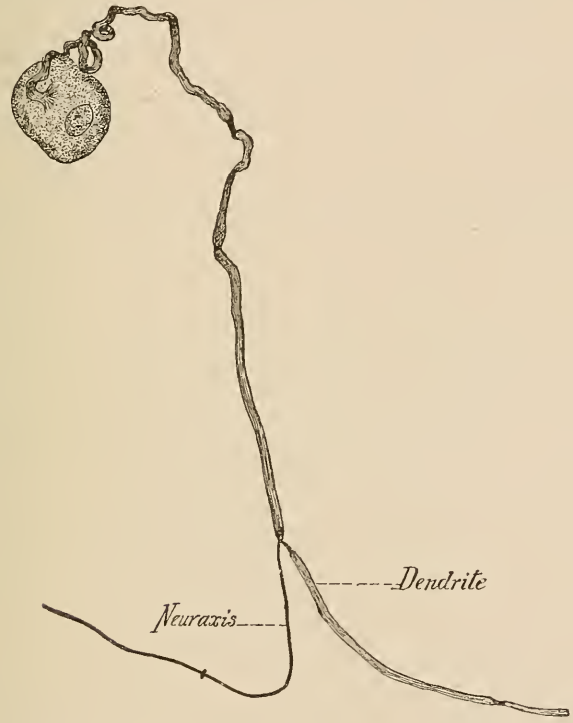


Fig. 66.—Ganglion cell from the Gasserian ganglion of a rabbit; stained in methylene-blue (*intra vitam*) (Huber).

the motor fibers that come from nerve cells in the anterior horn of the spinal cord and extend, without interruption, to muscles in the distal parts of the limbs. The axis cylinder presents a longitudinal striation, a fibrillar structure, that is supposed to be continuous with the cytoplasmic striation of the

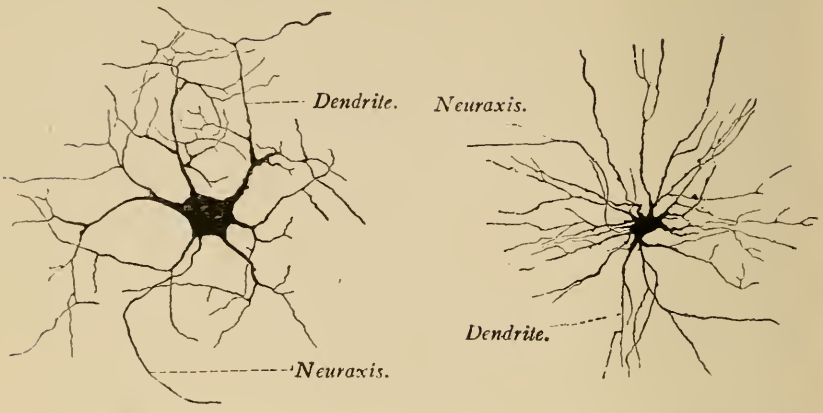


Fig. 67.—Motor neurons from the anterior horn of the spinal cord of a new-born cat; chrome-silver method (Huber).

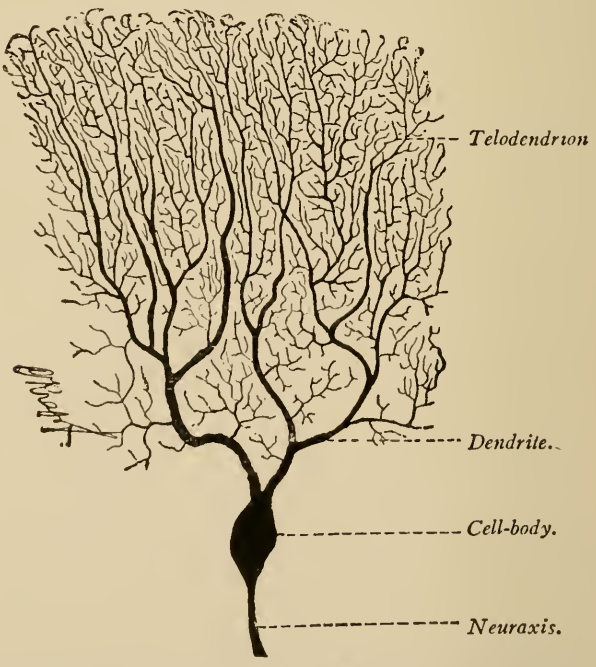


Fig. 68.—A nerve cell with branched dendrites (Purkinje's cell), from the cerebellar cortex of a rabbit; chrome-silver method (Böhm and Davidoff).

cell body. The *fibrils* are imbedded in a fluid protoplasmic substance, the *neuroplasm*, and the whole surrounded by a delicate membrane, the *exolemma*. *Implantation cone* is an elevation that is sometimes

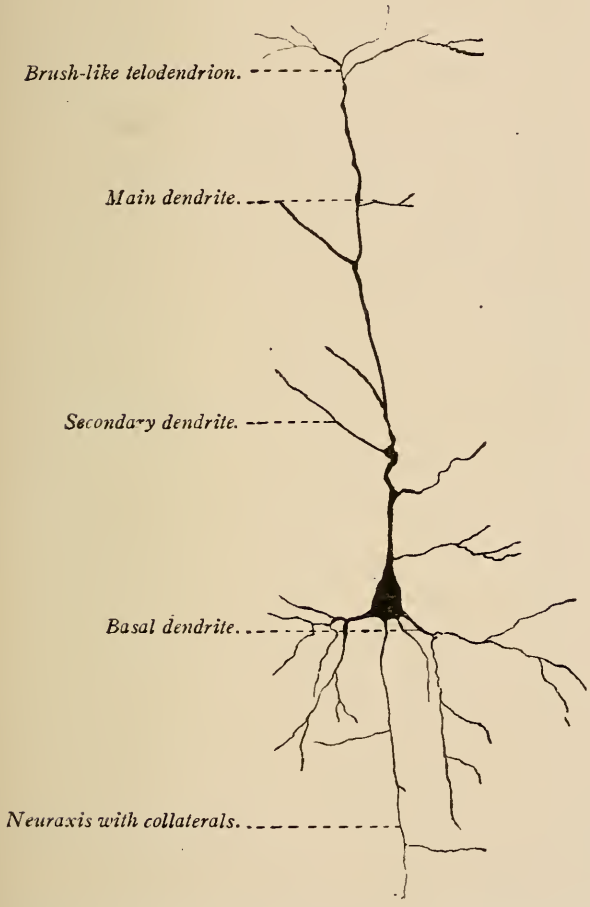


Fig. 69.—Pyramidal cell from the cerebral cortex of man; chrome-silver method (Böhm and Davidoff).

present at the junction of the axis cylinder and cell body.

The *medullary sheath* (white sheath of Schwann) is a covering to the axis cylinder. This sheath never

extends to the nerve cell but begins a little distance from it. It consists of fat and *neurokeratin*. The latter, on burning, gives an odor of burnt bone. It

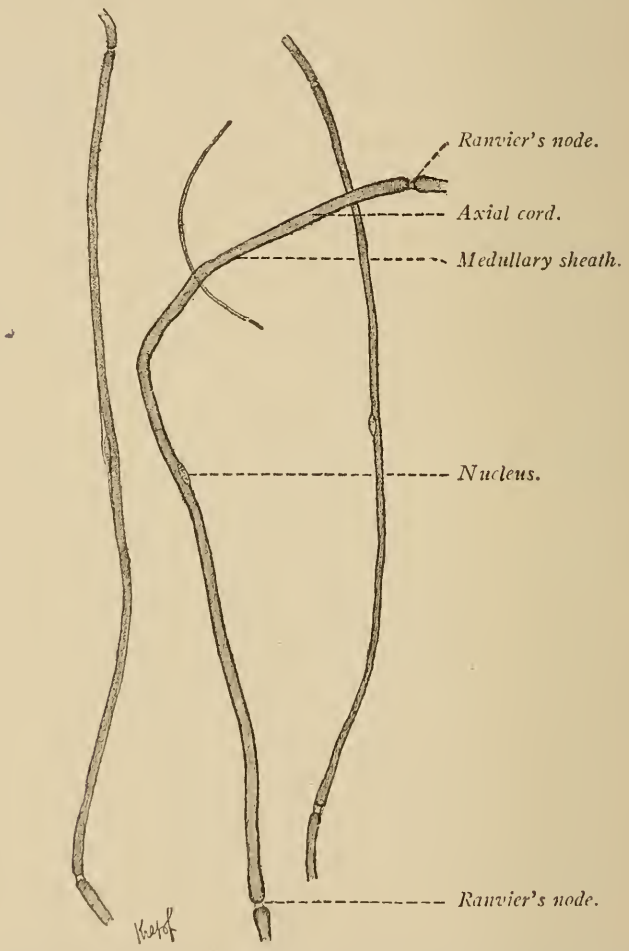


Fig. 70.—Medullated nerve fibers from a rabbit, varying in thickness and showing internodal segments of different lengths. In the fiber at the left the neurilemma has become slightly separated from the underlying structures in the region of the nucleus (Böhm and Davidoff).

is this sheath that gives the white color to nerves and the white matter of the brain. In osmic acid preparations, oblique fissures appear in the medullary sheath dividing it into sections known as *Schmidt-*

Lantermann segments. It is claimed by some that these are artifacts. *Nodes of Ranvier* are constrictions of this sheath at regular intervals of 80 to 900 μ. The smaller the fiber, the greater the distance between these nodes. Long fibers are slender, with long distance between the nodes; short fibers are coarse, with short distance between the nodes. Furthermore, in young fibers and at the distal portion of nerve fibers the nodes are relatively closer together.

The *neurilemma* is a thin structureless membrane that surrounds the medullary sheath. An oval nucleus is present in this sheath, midway between the nodes of Ranvier. At each node the neurilemma is constricted and touches the axis cylinder, which in turn may be slightly thickened at this point and may give off a collateral. Medullated nerve fibers with a neurilemma are found in the cranial and spinal nerves. Medullated fibers without a neurilemma are found in the brain and spinal cord. The neurilemma gives great strength to the fibers. Its absence in the brain and cord accounts for the pulpy, soft nature of this tissue.

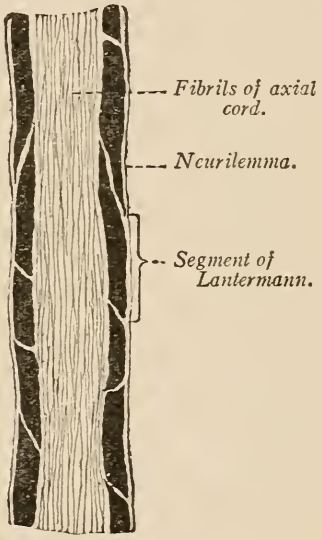


Fig. 71.—Longitudinal section through a nerve fiber from the sciatic nerve of a frog (Böhm and Davidoff).

2. *Non-medullated nerve fibers* with a neurilemma, but without a medullary sheath, mingle with the medullated fibers. The sympathetic system con-

sists largely of non-medullated fibers. Terminal branched endings of an axis cylinder, called *neuropodia*, have neither medullary sheath nor *neurilemma*. The axis cylinder, just as it leaves its nerve cell, is likewise uncovered.

Nerve Trunk.—The fibers that constitute a nerve are grouped into bundles called *funiculi*. Each funiculus is enclosed in a connective-tissue sheath, the *perineurium*, which sends septa, the *endoneurium*, in among the individual fibers. The whole nerve is enclosed in a firm connective-tissue sheath, the *epineurium*. Blood- and lymph-vessels accompany the connective-tissue elements and ramify through the nerve just as is the case in a muscle.

Fig. 72.—Remak's fibers (non-medullated fibers) from the pneumogastric nerve of a rabbit (Böhm and Davidoff).

Nerve cells with a long axis cylinder were classified by Golgi as Type I, and with a short axis cylinder as Type II. Golgi believed the former to be motor in function, and the latter sensory, a classification no longer tenable.

Neuroglia tissue is a delicate supporting tissue of the brain and cord, consisting of cells with many fine interlacing branches, *mossy cells*, or *spider cells*. These cells develop from the ectoderm and are ontogenetically closely related to nerve cells. Their function is to give support, not to conduct nerve impulses.

The great nerve center in the body is the *cerebro-*

spinal system—brain and spinal cord. Next comes the *sympathetic system*, made up of ganglia and

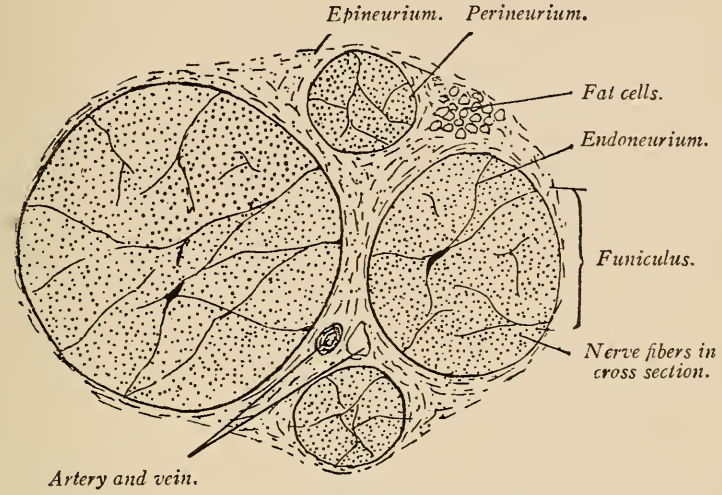


Fig. 73.—Cross section of nerve trunk

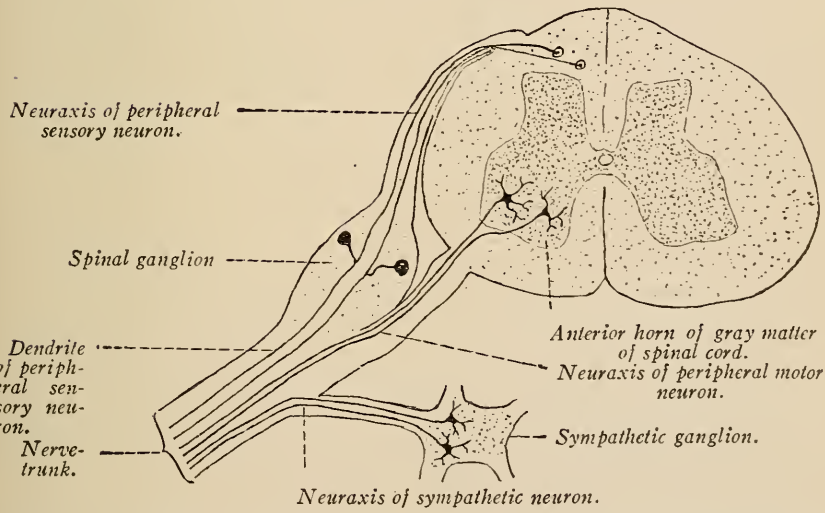

Neuraxis of peripheral sensory neuron.
Spinal ganglion
Dendrite of peripheral sensory neuron.
Nerve-trunk.
Anterior horn of gray matter of spinal cord.
Neuraxis of peripheral motor neuron.
Sympathetic ganglion.
Neuraxis of sympathetic neuron.

Fig. 74.—Diagram to show the composition of a peripheral nerve-trunk (Huber).

mostly non-medullated nerve fibers that terminate in glands or smooth muscle. Lastly, the peripheral

system,—nerve terminations formed in tissues and organs throughout the whole body.

General Considerations.—Nerve cells are so highly specialized that their multiplication after birth is unknown. We never, therefore, find tumors of nerve cells. If a nerve cell is cut, the axis cylinder removed from the nerve cell dies while the end that is still attached to the cell regenerates and may

Fig. 75.—Neurogliar cells: *a*, from spinal cord of embryo cat; *b*, from brain of adult cat; stained in chrome-silver (Böhm and Davidoff).

restore the lost part. Surgeons unite the ends of a cut nerve so that the axis cylinder may develop along the old nerve trunk which becomes a path of least resistance.

In amputations the cut nerve may grow into a tumor, called a *neuroma*. Such a tumor would consist of nerve fibers and the accompanying connective-tissue elements. Injury to nerve cells, such as

brain or ganglia, heal by production of connective tissue and accompanying scar.

The function of the axis cylinder is to conduct a nerve impulse. Physiologically such an impulse travels away from the cell, but experimentally it may pass in the opposite direction, as is the case when a nerve is stimulated midway in its course. The axis cylinder being made up of fibrils, it follows that such a cylinder may conduct more than one impulse, which in turn reach different centers through different collaterals.

The function of the medullary sheath is to protect and nourish the axis cylinder. Experimentally the non-medullated nerve fibers will tire quicker than the medullated. The nodes of Ranvier are points where nourishment from the blood and lymph can reach the cylinder. It is affirmed by some that the endolemma is only a lymph space surrounding the axis cylinder.

The neurilemma is protective in function and gives great strength to the fibers. With nerves that terminate in muscle fibers the neurilemma is continuous with the sarcolemma of the muscle. Proximally the neurilemma begins where the medullary sheath takes up, always a short distance from the nerve cell, which leaves the axis cylinder uncovered as it emerges from the cell.

It is affirmed that the neuron represents the elementary unit of nerve tissue, and that neurons are merely in contact with each other and not in protoplasmic continuity. This idea constitutes the neuron theory.

CHAPTER III.

CIRCULATORY SYSTEM, BLOOD, MARROW, AND LYMPHATIC ORGANS.

HEART.

The heart is a muscular organ. Its wall consists of three layers, *endocardium*, *myocardium*, and *epicardium*.

1. The **endocardium** is a serous membrane that covers the inner surface. Histologically it consists of two layers, an inner lining of simple squamous epithelial cells (endothelium or mesothelium), and an outer layer composed of connective-tissue fibers, connective-tissue cells, and smooth muscle cells. The endocardium is reflected over the heart valves where the smooth muscle is particularly abundant.

2. The **myocardium** is the middle layer and forms the mass of the heart wall. It consists of muscle tissue, the *cardiac muscle* already described (page 87). This muscle consists of many layers that course in different directions with connective-tissue elements intervening, in which branches of the coronary blood-vessels ramify.

3. The **epicardium** is the outer covering, a serous membrane, and histologically similar to the endocardium, with a greater deposit of fat. The epicardium is reflected to form the *pericardium*, the

epithelial cells secreting a serous fluid that acts as a lubricant.

ARTERIES AND VEINS.

Arteries.—The arteries convey blood from the heart to the capillaries, and vary in size from the aorta, the largest, down to minute structures of microscopic caliber. The walls of these vessels are composed of three layers: *tunica intima*, *media*, and *adventitia*.

1. *Tunica intima* is the internal coat and is a very

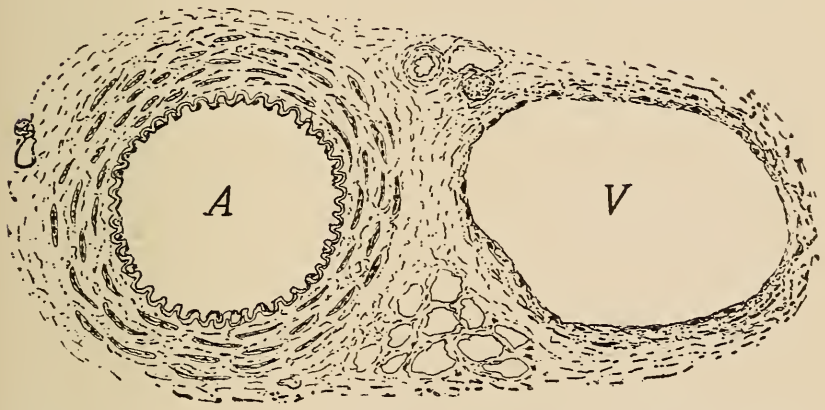


Fig. 76.—Cross section of small artery and vein; *A*, artery; *V*, vein.

thin, smooth, glassy membrane, often difficult to demonstrate in sections. This is again divided into three layers, the innermost being a layer of pavement *endothelial cells*, outside of which we find a delicate fibrous connective-tissue fabric, the *subendothelium*, and outside of this again a layer of elastic fibers called the *fenestrated membrane of Henle*. The *endothelial layer* is made up of a single layer of flattened cells, held together by a cement substance and analogous to the endothelium of the peritoneum

and pleura already described. These cells are plastic, loosely attached to the subendothelium, and form a slippery surface over which the arterial blood flows rapidly. Any damage to these cells results quickly in the formation of a small blood-clot at the point of injury, from which we infer that they play a most important physiological rôle in their relation to the blood stream. The *subendothelium* is made up of a delicate network of elastic fibers, enclosing a few connective-tissue cells, which allows the applied endothelium a limited amount of mobility. The *fenestrated membrane of Henle* (called the internal limited membrane of the media by some authors) consists of a coarser elastic network of heavier elastic fibers which when peeled away as a whole presents on the exposed surface a basket-work arrangement of its fibers with numerous intervening elongated apertures like so many windows, hence its name. This membrane in cross-section of arteries appears as a wavy or corrugated white line encircling the artery very near to its inner surface.

2. *Tunica Media.*—This is the middle layer of an artery, and makes up the bulk of its wall. In small arteries a considerable amount of smooth circular muscle fibers is always present, while in the larger arteries circular elastic and non-elastic connective-tissue fibers make up its bulk. A sprinkling of connective-tissue cells may be seen, also a limited amount of longitudinal muscle and connective-tissue elements. A few blood capillaries and lymphatic spaces are present, which always connect with a

coarser vascular system of the outer layer, never directly with the blood within the artery through the intima. Of course, nerve endings are found, which can only be demonstrated in specially prepared sections.

3. *Tunica Adventitia.*—This is the outer layer,

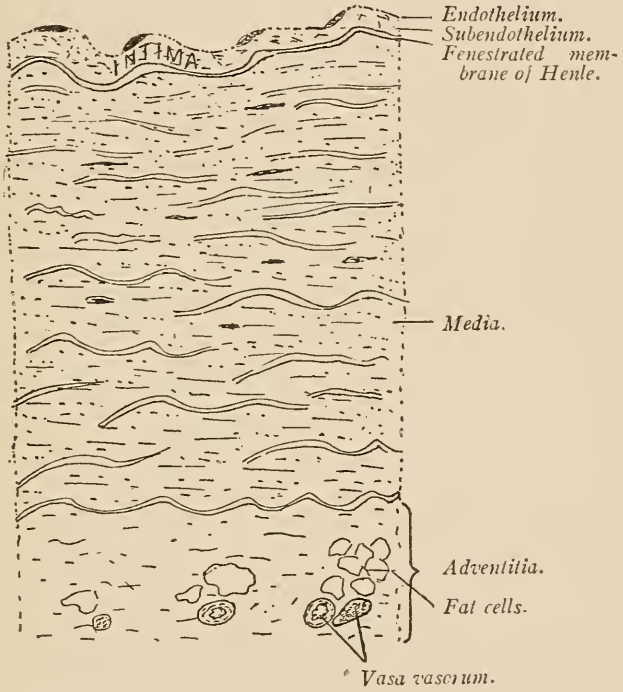


Fig. 77.—Cross section of aorta.

and is made up of a loose arrangement of tissues, and, taken as a whole, is less definitely defined than the media. It varies in thickness according to the location of the artery, but, as a rule, it is not so wide as the media; while in the media the connective-tissue fibers are arranged in sheets which interlace with any muscle that may be present, in the adventitia the fibers form diagonal bundles, mostly of the

non-elastic kind, which mingle with the adjacent areolar tissue with which arteries are nearly always associated. These bundles often serve as support to organs, by which the latter are more firmly anchored. From such a union between the vena cava and abdominal aorta to the liver this organ receives a substantial support. The kidneys and ovaries are organs that may be cited as benefiting greatly by such a connection. A considerable amount of fat is often present in the adventitia, also connective-tissue cells, nerves, a few smooth muscle fibers, lymphatics, and blood-vessels. The latter are called *vasa vasorum*, and play an important part in the nourishment of the arterial wall. The vasa vasorum are sub-branches derived usually from some small branch of an adjacent artery, but may come directly from a small branch of the same artery which is given off at a higher point.

As stated before, large arteries have relatively a large amount of elastic fibers and a small amount of smooth muscle. The aorta has scarcely any muscle. In the small arteries the reverse is true. The wall of large arteries is relatively thinner than that of small ones. The reverse is true of the intima. In large arteries the adventitia is also relatively scant, while in the smaller ones the adventitia may be one-half to two-thirds the thickness of the media. On account of the rigid and elastic arterial wall these vessels are usually empty after death, contracted but retain their normal shape; while veins, on the other hand, collapse and usually contain a certain amount of blood.

Veins.—These vessels convey the blood from the capillaries back to the heart. The progressive increase in size and the thickness of their walls is accompanied by a relative increase in blood pressure and rate of blood flow, yet nowhere is this equal to what obtains in the large arteries. Structurally we find the same layers in veins as in arteries, with the chief difference that the vein wall is much thinner. The endothelial layer of cells is supported by a very thin layer of delicate connective-tissue fibers, mostly non-elastic, while the fenestrated membrane of Henle is incomplete and usually difficult to demonstrate. The media, as in arteries, is the most prominent layer, but, unlike arteries, the non-elastic fibers prevail. Smooth muscle fibers, mostly circular, are often significant in this layer, while the other tissue elements are less conspicuous. The adventitia resembles more closely that found in arteries, with perhaps even less of the elastic elements and more of the smooth muscle cells. Comparing the different sizes of veins, we find an excess of elastic and muscular tissue in large veins. In the pulmonary vein the circular muscle fibers are well developed, while in the large cranial veins, such as the meningeal sinuses, muscle tissue is almost entirely absent. Veins, like arteries, therefore, show a structural variation, depending not only on size, but on location. It should be mentioned that in many superficial long veins, like those of the legs and neck, valves are present in the form of crescentic folds of the intima which function in overcoming the pressure of blood due to gravity. Those of the

neck are so placed as to become functional when an animal lowers its head, as in the act of grazing.

Summary of Arteries and Veins.

I. Tunica intima.
   1. Endothelium, simple squamous epithelial cells.
   2. Subendothelial layer.
      *(*a*) White connective-tissue fibers.
      (*b*) Connective-tissue cells.
      †(*c*) Elastic connective-tissue fibers.
   †3. Henle's fenestrated membrane (elastic internal limiting membrane). Interlacing basketwork of elastic fibers.

II. Tunica media.
   †1. Smooth muscle, circular.
   †2. Elastic plates and fibers, longitudinal and circular.
   3. Nerves.
   4. Blood capillaries, difficult to demonstrate.
   *5. White connective fibers.
   6. Connective-tissue cells.
   7. Muscle fibers longitudinal, rare.

III. Tunica adventitia.
   *1. White connective-tissue fibers, longitudinal and oblique.
   2. Connective-tissue cells.
   †3. Elastic connective-tissue fibers, longitudinal (external limiting membrane).
   4. Nerves.
   5. Vasa vasorum (blood-vessels).
   6. Lymphatic vessels and nodes.
   *7. Smooth muscle fibers.

It should be remembered that structural difference in large and small arteries is in keeping with their function. In small arteries or arterioles, the involuntary muscle is conspicuous, as it is the contraction of this muscle that regulates the blood supply to an organ. In large arteries, as the aorta, the muscle is

* This tissue predominates in veins.
† This tissue predominates in arteries.

unnecessary and is greatly reduced, while elastic elements are unusually well developed. The muscle, too, is deficient in large veins situated deep in the body, as the vena cava. Many of the smaller and more superficial veins have valves, folds of the intima, so arranged as to equalize the gravity pressure of the contained blood. Without these valves the thin-walled veins would become greatly distended. If for any cause the veins expand so that the valves do not act, a permanent distention with engorgement of blood follows. The veins become distorted and are spoken of as *varicose veins*, a condition quite common to the long saphenous veins of the lower limbs.

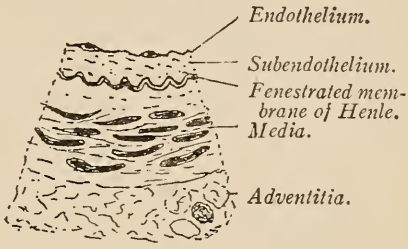


Fig. 78.—Cross section of small artery.

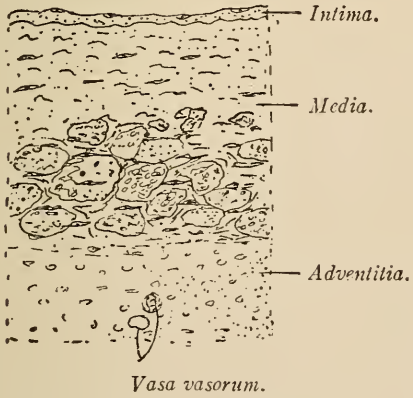


Fig. 79.—Cross section of vein.

Capillaries. — These are the finer organic ramifications of the circulatory system, and unite arteries and veins. Histologically, the walls of capillaries consist of a single layer of flattened epithelial (endothelial or mesothelial) cells. The blood courses very slowly through these interlacing tubes. The white cells penetrate the walls and under certain conditions even the red corpuscles

may do so. According to some investigators, minute pores in the epithelial wall, called *stigmata* and *stomata*, allow this migration. Others deny the presence of these spores, in which case the blood elements escape by passing between two adjacent epithelial cells, after which this opening closes.

THE BLOOD.

The blood is derived from the mesoderm; it is a red fluid that consists of (1) a liquid portion, the plasma, and (2) solid constituents, the corpuscles. There are at least three classes of the latter, *red corpuscles*, *white corpuscles*, and *platelets*.

Fig. 80.—Red blood-corpuscles from man.

1. **Red corpuscles** (erythrocytes) in the mammalia are non-nucleated, circular, biconcave discs. In all the other vertebrate groups and in all embryos they are *nucleated oval and biconvex cells*. Each corpuscle consists of a red coloring matter, *hemoglobin*, and a more substantial fabric or reticulum, the *stroma*. The hemaglobin is the bearer of oxygen, is readily soluble in water, leaving the stroma or fabric, which is then known as a *ghost corpuscle*.

The red corpuscles are soft and elastic and are covered by an oily film. In a fresh spread they adhere to each other by their concave surfaces forming *rouleaux* or "*money-*

pile" rows. This is purely a physical phenomenon. As soon as the oily covering dissolves this combination disappears. The corpuscles are extremely susceptible to changes in the plasma. If water is added they will swell up and the hemoglobin begins to dissolve. With evaporation the corpuscles begin to shrink, forming minute processes and they are then said to be *crenated.* Evaporation of water produces an increased percentage of the salts in solution. This in turn abstracts water from the corpuscles and the shrinking or crenated condition follows.

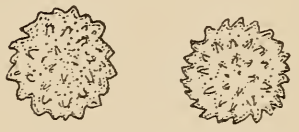


Fig. 81.—Crenated red blood-corpuscles from man.

It is estimated that the total amount of blood in man is one-thirteenth the weight of the body. The average normal male, therefore, has approximately 25,000,000,000,000 red corpuscles. The life period of a red

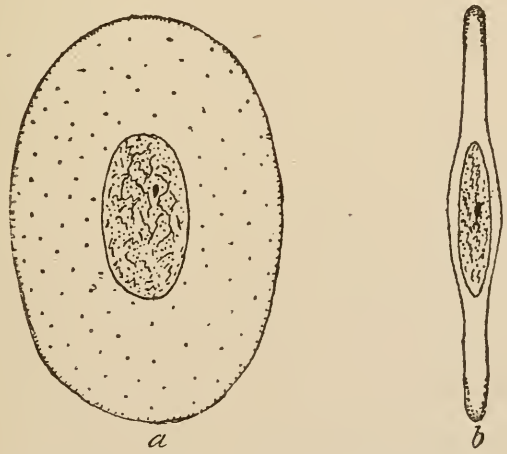


Fig. 82.—Red blood-corpuscle of frog; *a*, flat view; *b*, side view.

corpuscle is not definitely known, but physiologists tell us it is probably from two to four weeks. Ac-

cordingly the daily consumption and loss is enormous, and is equaled only by as constant and regular a production of new cells. Their number in man is 5,000,000 per cubic millimeter.

The following table gives the size of the red blood-corpuscle in the different groups of animals:

Man	7.2 to 7.8 μ.	Chick	12.1 by 7.2 μ.
Monkey	7.0 μ.	Duck	12.9 " 8.0 μ.
Dog	7.5 μ.	Tortoise	21.2 " 12.5 μ.
Cat	6.2 μ.	Snake	22.0 " 13.0 μ.
Horse	5.6 μ.	Frog	22.3 " 15.7 μ.
Guinea-pig	7.5 μ.	Newt	30.7 " 19.0 μ.

White Corpuscles.—These are colorless, nucleated, plastic, ameboid cells. Their number in man is from 7000 to 10,000 per cubic millimeter. They are variously classified according to the morphology of their nuclei, or the granules in the cytoplasm that

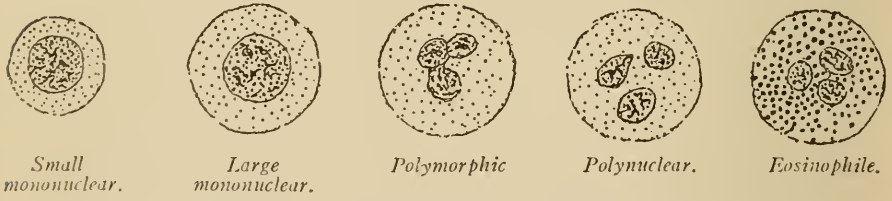


Fig. 83.—White blood-corpuscles from man.

take different stains, or as to their origin, or as to their function. For practical purposes they may be classified as:

1. Lymphocytes.....size 8 to 10 microns....22 per cent.
2. Large mononuclear leucocytes. " 10 to 15 " .... 4 " "
3. Polynucleated..... " 12 " ....74 " "
   (*a*) Mast cells..... 0.4 per cent.
   (*b*) Eosinophiles..... 2 to 4 " "
   (*c*) Neutrophiles ..... 70 " "

Lymphocytes are small, mononucleated, white corpuscles, with a distinct staining nucleus and a very narrow border of cytoplasm. Amœboid motion is, accordingly, much limited in this class.

Large mononucleated leucocytes have a large vesicular and usually eccentric nucleus. Its chromatin occurs in scattered granules that stain less deeply with nuclear stains, while the finely granular cytoplasm is usually abundant. These cells are generally regarded as phagocytic in function.

Polynuclear cells are only slightly larger than the red blood-corpuscles. The nuclei are often nodular, polymorphic; that is, are united by slender constrictions, or are lobulated and of a variety of patterns. In a small number of these cells basophilic granules are found in the cytoplasm, which stains blue with basic stains. These are the *mast cells*. Another small group have eosin-staining granules, and these are the *eosinophiles*. The large bulk of polynucleated white corpuscles have cytoplasmic granules that take neither acid nor basic stains, and these are the *neutrophiles*. They are the white corpuscles found abundantly in ordinary pus and the ones that produce a general leucocytosis in such infections.

The percentage of these different cells and their total number per cubic millimeter is of the greatest clinical value in blood analysis. They are often called *wandering cells*, as they are able to pass through the capillary wall and migrate throughout the tissues and organs. The polynucleated form is readily recognized by multiple or fragmented nuclei.

3. **Blood platelets** are small, colorless, round, non-nucleated bodies about one-third the size of red

blood-corpuscles. They are supposed to play an important rôle in the coagulation of blood. As soon

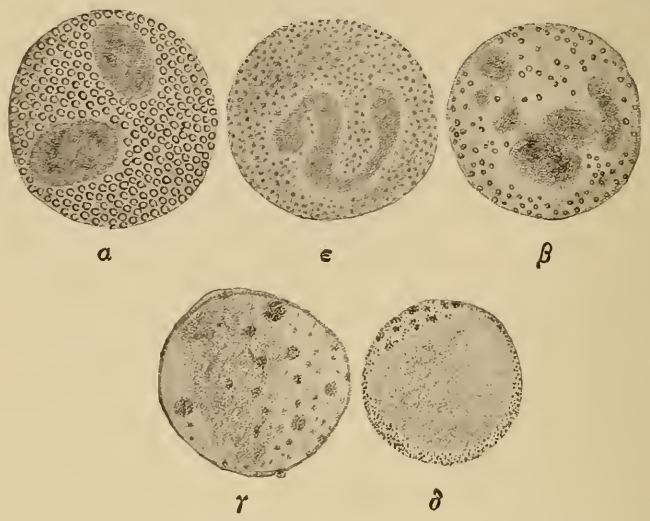


Fig. 84.—Ehrlich's leucocytic granules (from preparations of H. F. Müller): α, Acidophile or eosinophile granules, relatively large and regularly distributed; ε, neutrophile granules; β, amphophile granules, few in number and irregularly distributed; γ, mast cells with granules of various sizes; ∂, basophile granules; (α, ∂, and ε, from the normal blood; γ, from human leukemic blood; β, from the blood of guinea-pig) (Böhm and Davidoff).

as blood is shed most of them disappear, unless special precaution is made to preserve them. They may be preserved by pricking the finger through a drop of osmic acid. Their number per cubic millimeter is from 200,000 to 600,000.

According to Wright's investigations, these platelets represent detached portions of giant cells found in bone-marrow or in the spleen. Schäfer regards them as minute cells, while others think of them as fragments of red or white corpuscles.

Hemin Crystals (Teichman's crystals).—These come from the hemoglobin of the blood, and when found are always a positive evidence of blood. The crystals can be obtained from clotted blood, no mat-

ter how old the clot or stain is. Dry blood and salt, equal parts, are ground together on a glass slide, a few drops of glacial acetic acid are added and heat applied until gas-bubbles appear. The crystals are brown, rhombic, and easily recognized.

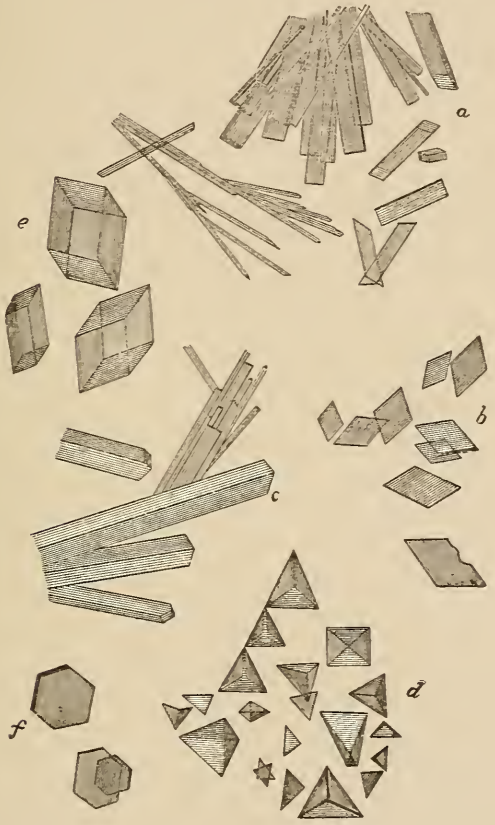


Fig. 85.—Crystallized hemoglobin: *a*, *b*, Crystals from venous blood of man; *c*, from the blood of a cat; *d*, from the blood of a guinea-pig; *e*, from the blood of a hamster; *f*, from the blood of a squirrel (after Frey).

MARROW.

Bone marrow is either white or red. The white marrow occupies the shaft of the bone and is largely fat. The red is found in the ends of bones or cancellated portions and is richly supplied with blood.

Histologically, we find in marrow all the constituents of blood and connective-tissue elements, fibers and cells. In addition, the following are some of the more characteristic cells of this tissue:

1. *Hematoblasts* or *Nucleated Red Blood-corpuscles.*—These cells contain hemaglobin and a small round nucleus that stains heavily with hematoxylin. They are supposed to be the chief source of the red blood-corpuscle, in which case the nucleus must disappear either by disintegration or extrusion.

2. *Marrow Cells* or *Myelocytes.*—These are large cells with a rather large nucleus that stains lightly.

3. *Eosinophiles.*—These are destined to become the eosinophile of the blood.

4. *Giant Cells* (myeloplaxes or osteoclasts).—These are very large polynucleated cells, having from ten to twenty nuclei. Cells of this class are not numerous, but extremely large (30 to 100 μ). They may be found in the fetal liver or spleen, and are very characteristic of developing bone. They present a finely granular protoplasm without any cell wall. The many nuclei are bunched about the center of the cell, and in this respect they differ from the giant cells found in tuberculosis foci, in which the nuclei are found near the periphery. They multiply by mitosis, and primarily are supposed to be derived from leucocytes by endogenous division of their nuclei. These remarkable cells have usually been regarded as the active agents in bone absorption, but recently Wright has suggested that blood platelets

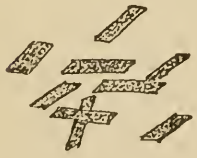


Fig. 86.—Hemin, or Teischman's crystals from blood-stains of man.

may be derived from their cytoplasm by a process of budding or by particles merely breaking away.

General Considerations.—There is an old saying that "a person is as old as his blood." A truer expression would be that he is as old as his blood-vessels. With age, or dissipation, the blood-vessels harden, due to depositions of connective-tissue elements. This impairs the free circulation of blood and the body, as a whole, suffers. The hardened condition is spoken of as *arteriosclerosis*, or *atheroma*. Usually the intima suffers first by becoming much thickened. Later, a like disturbance takes place in the media and adventitia. As superficial scars remain permanently, and can not be eliminated, so there is no relief for this scar formation of the blood-vessels. Under this hardened condition a rupture of the smaller arteries is not uncommon, particularly those of the brain, as they have thinner walls. Such a disaster is apt to be fatal.

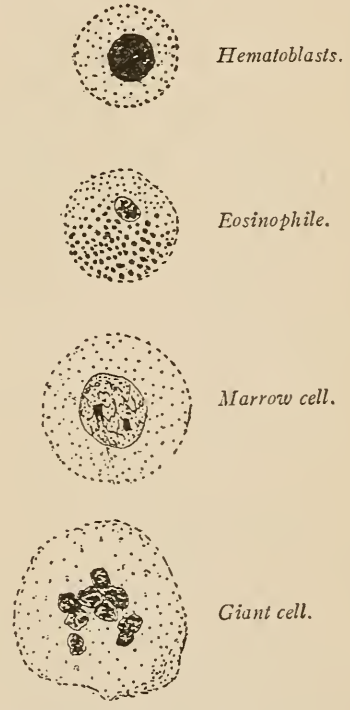


Fig. 87.—Cellular elements of red marrow.

An inflammation of the heart, as endocarditis, is apt to produce a deposit of connective tissue in the endocardium, which upon shrinking brings about defective valves, with leakage of blood. This increases the work of the heart, and although that organ in an emergency can do

twenty times its normal work, there is of course a limit to its power, and broken compensation sooner or later follows.

The *vasa vasorum*, that carry blood to nourish the walls of both arteries and veins, are very important structures. The coronary vessels of the heart belong to this class and their course is quite definitely known. Our knowledge of the rest is vague. They ramify through the adventitia and to a less extent in the media. If a blood-clot forms within the vessel, loops from the vasa vasorum enter the clot and assist in its organization.

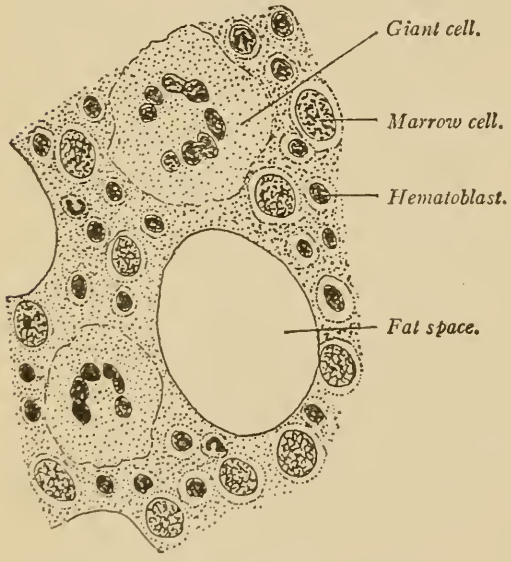


Fig. 88.—Section of red marrow.

The endothelial cells of the intima, according to one theory, are active agents in preserving the fluid condition of the blood; that is, inhibiting coagulation. If these cells are injured a clot of blood quickly forms upon the injured or denuded surface. Surgeons take advantage of this principle and twist or crush the ends of bleeding vessels to check a hemorrhage.

The disintegration of red blood-corpuscles is known as *hemolysis*, and may be produced by injecting into the circulatory system certain poisons, or mixing extravasated blood directly with these poisons.

Hemolysis occurs in various diseases and is one of the chief changes observed in making a Wassermann test.

The identification of blood-stains is often a medico-legal problem. The corpuscles of the blood preserve their integrity for a remarkably long period of time, so that in a water solution of even an old clot,

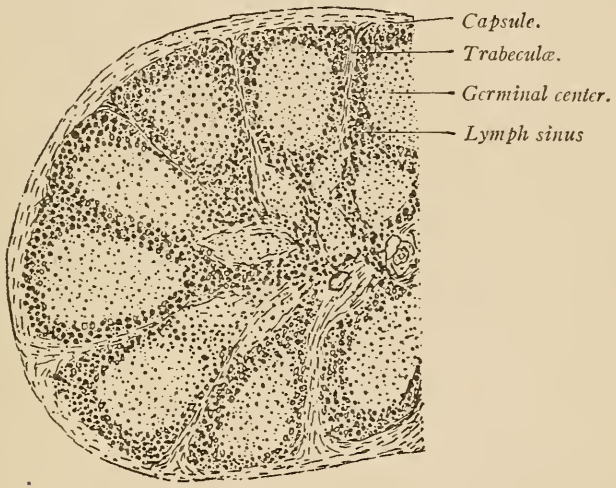


Fig. 89.—Section of lymph node.

the red blood-corpuscles are readily detected under the microscope. Hemin crystals is another evidence that the stain is blood. To identify the blood of man is practically impossible. Non-mammalian blood, as that of a bird, can usually be positively recognized by the nucleated red blood-corpuscles and their oval form. The practical value of this in criminal cases is apparent.

LYMPHATIC SYSTEM, THYMUS, AND SPLEEN.

1. **Lymphatic Capillaries.**—The walls of these capillaries consist of a single layer of flattened epithelial cells (mesothelial or endothelial). They

therefore, histologically, resemble the blood-capillaries. They are not so well defined but represent rather irregular cavities with numerous constrictions. These capillaries, according to one theory, form a closed system and open only into the larger vessels.

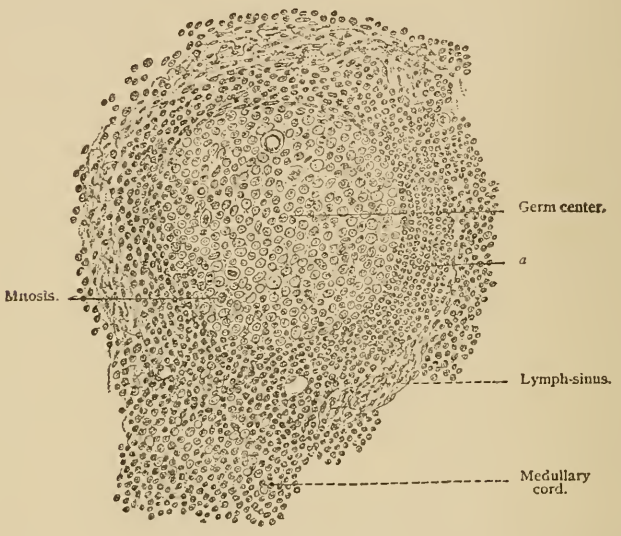


Fig. 90.—From a human lymph gland. At *a* are seen the concentrically arranged cells of the lymph nodules (fixation with Flemming's fluid) (Böhm and Davidoff).

Another theory is that at their origin they communicate with intercellular spaces.

2. **Lymphatic Vessels.**—These accompany blood-vessels and have very thin walls. Ultimately they drain into the large thoracic lymph duct or the short right lymphatic duct; each finally opens into the venous system at the junction of the subclavian and jugular veins. The thoracic duct begins with the *receptaculum chili*, just below the diaphragm and a little to the right of the vertebræ, passes upward into the thorax to open into the venous system on the

left side, as given above. The histology of the walls of these vessels resembles that of the veins.

3. **Lymph Glands.**.—These represent *adenoid tissue*, and consist of (1) *reticular connective tissue* and (2) *lymph cells*. Lymph glands are found throughout the body in connection with lymph vessels, fat and connective tissue. They serve as filters to the lymph

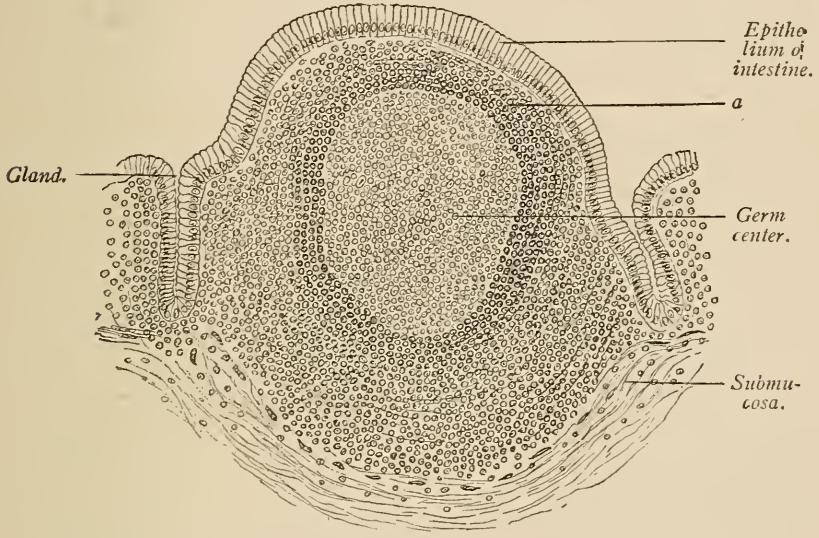


Fig. 91.— A solitary lymph nodule from the human colon. At *a* is seen the pronounced concentric arrangement of the lymph cells (Böhm and Davidoff).

and contribute white corpuscles to the blood. Structurally, these nodes have a connective-tissue *capsule*, that sends filaments into the node, called *trabeculæ*. Within these meshes lymph cells are densely packed around the periphery of *secondary nodules*, which in turn occupy the cortex of each node. The center of each nodule is known as the *germ center* or *lymph pulp*. The periphery of each secondary nodule, being densely packed with white lymph-corpuscles, takes a darker stain than the

center. The space occupied by these white corpuscles is called the *lymph sinus*. The cells of the sinus are in circulation while those of the germ center remain stationary.

Lymph glands represent adenoid tissue and consist of two elements, (*a*) reticular connective tissue, with many elastic fibers, and (*b*) lymphoid cells. An inflammation of this tissue is therefore called adenitis. Blood-vessels and nerves ramify through this tissue. They enter at one point called the hilum. Lymph vessels connect with opposite points of the node, the efferent one passing out at the hilum. The

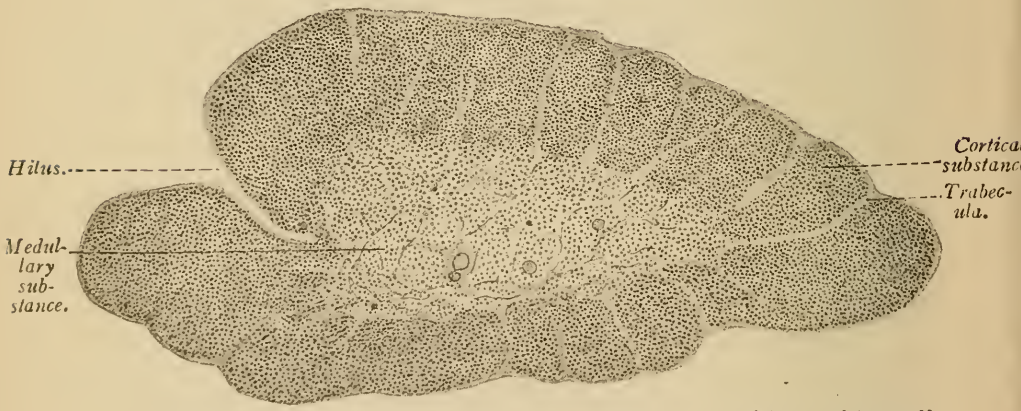


Fig. 92.— A small lobule from the thymus of child, with well-developed cortex, presenting a structure similar to that of the cortex of a lymph gland (Böhm and Davidoff).

efferent quickly unites with a second node to which it becomes the afferent vessel. In this way the lymph nodes are united into chains, always accompanying blood-vessels and fascia.

Solitary lymph nodes are found just beneath the epithelium of mucous membranes, particularly in the alimentary tract. They resemble secondary nodules of lymph nodes. In the lower part of the

ileum they are collected into patches called *agminated lymph nodules* or *Peyer's patches*.

Hemolymph Glands.—These resemble the lymph nodes described above, except that the lymph sinus is filled with blood. When first discovered they were believed to be evidence of disease, but they are now looked upon as normal structures. They are most readily found in the fascia involving the thoracic aorta, and are particularly abundant in the sheep.

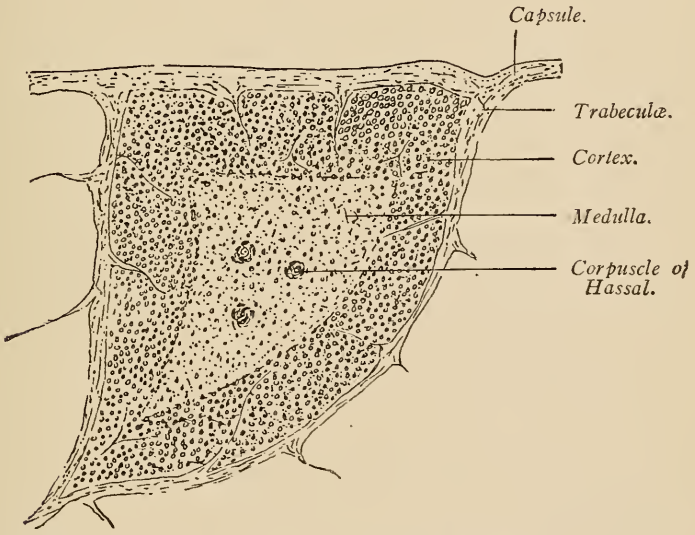


Fig. 93.—Section of lobule of thymus gland.

THYMUS GLAND.

The thymus gland is described in this place because of its resemblance in the adult to a lymph organ. In the embryo it is an epithelial organ that develops from the hypoderm of the third and fourth visceral clefts. Lymphoid tissue invades this epithelium and reaches its highest development in a child two years old. After this age the lymphoid tissue is

invaded by connective tissue and fat, so that at the age of puberty only a remnant of the original structure remains.

In the child the thymus is a paired, elongated, lobulated, ductless organ that lies partly in the neck and partly in the thorax upon the large blood-vessels. Structurally we recognize a *capsule* with *trabeculæ*, *pulp* and the *corpuscles of Hassal.*

1. *Capsule and Trabeculæ.*—The capsule consists of dense connective tissue, mostly nonelastic fibers and cells. Processes or *trabeculæ* pass into the organ from the capsule and divide it up into distinct angular lobules. Fibers from the trabeculæ enter the lobules where they interlace to form a supporting reticulum.

2. *Pulp.*—This consists of lymphoid cells that fill the intersticies of each lobule. The cells are more densely packed along the periphery of each lobule, so that an outer or *cortical layer* can be distinguished from a central portion, the *medulla.*

Fig. 94.—Corpuscle of Hassal surrounded by lymphoid cells from the medulla.

3. *Corpuscles of Hassal.*—These are nests of epithelial cells that lie in the medulla and are remnants that show the epithelial origin of the organ. They stain red with eosin and are found in no other organ. It is affirmed that these epithelial cells continue to grow after birth and may be found late in life when only remnants of the thymus is present.

SPLEEN.

The spleen is a blood-forming organ, very vascular, purple in color, and with a density slightly more than that of the liver. It varies greatly in size, the average being five inches long and three inches wide. Its surfaces touch the left kidney, the cardiac end of the stomach, and the left lower aspect of the diaphragm. Its long axis follows the direction of the tenth rib. It is practically covered by the

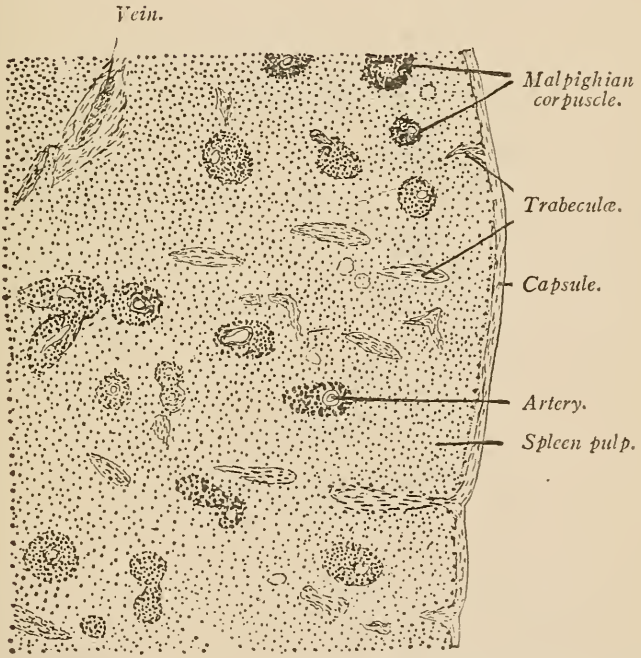


Fig. 95.—Portion of section of human spleen. The figure gives a general view of the structure of the spleen (Sobotta).

peritoneum. The structures to be recognized are *capsule* and *trabeculæ*, *Malpighian corpuscles*, and *spleen pulp*.

1. *Capsule and Trabeculæ.*—The investing peritoneum forms a serous coat with simple squamous

epithelium and connective-tissue fibers. Subjacent to this the spleen is provided with a strong capsule consisting of elastic fibers, connective-tissue cells and involuntary muscle. The spleen is thus not only distensible but may pulsate. From the deep surface of the capsule processes or *trabeculæ* of connective tissue and smooth muscle pass into the substance of the spleen. From the trabeculæ finer branches pass to form a fine supporting fabric for the whole organ.

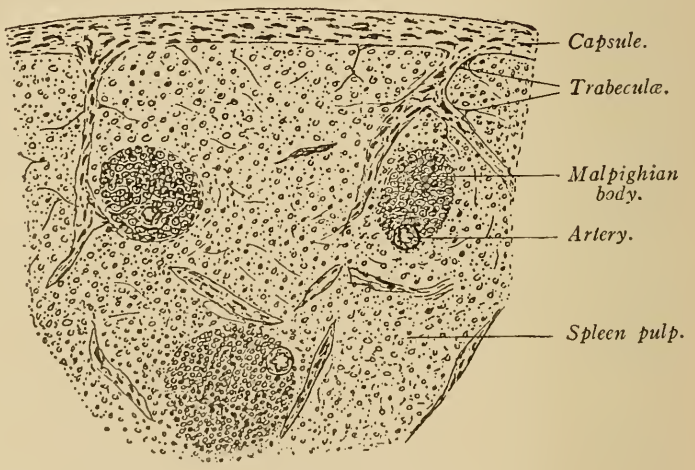


Fig. 96.—Section of spleen.

2. *Malpighian Corpuscles.*—These are lymph pockets in the adventitia of the smaller arteries. The artery rarely passes through the center of the corpuscle, but usually eccentric to or one side of it. The lymph corpuscle is liberally supplied with blood.

3. *Spleen Pulp.*—This constitutes the bulk of the spleen and fills the spaces between the trabeculæ. The constituent corpuscles of the blood are present in this pulp and *splenic cells.* The latter are slightly

larger than white blood-corpuscles, are mononucleated and contain pigment and frequently red blood-corpuscles.

Blood Supply.—The splenic artery enters the hilum and its branches follow the trabeculæ. Ultimately the smaller branches enter the spleen pulp. Beyond the Malpighian bodies the smaller arteries end in minute dilatations known as the *ampullæ of Thoma*. Beyond these the blood flows directly into the meshes

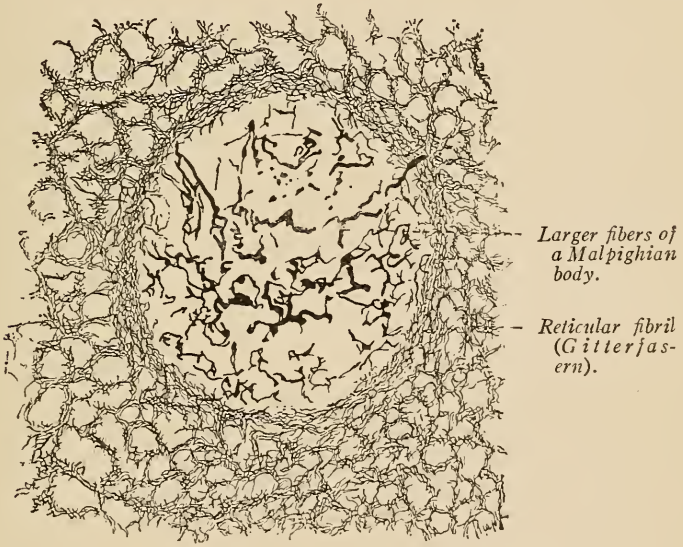


Fig. 97.—From the human spleen (chrome-silver method) (Böhm and Davidoff).

of the spleen pulp with no other walls than the spleen cells. The veins begin in the same way as the arteries end. The capillary veins pass directly to the trabeculæ and ultimately unite at the hilus to form the splenic vein which drains into the portal.

General Considerations.—The invasion of bacteria into the system is chiefly along the lymphatics. Each lymph node becomes a point of resistance, and

usually enlarges many times the normal size, far in advance of the seat of infection. This is due to the absorption of the toxins. Thus the lymph nodes in the groin enlarge from an infection in the toe, those in the axilla from an infected finger, and those of the neck from a bad tooth. If these barriers break down the infection becomes systemic, a condition known in a general way as blood-poisoning.

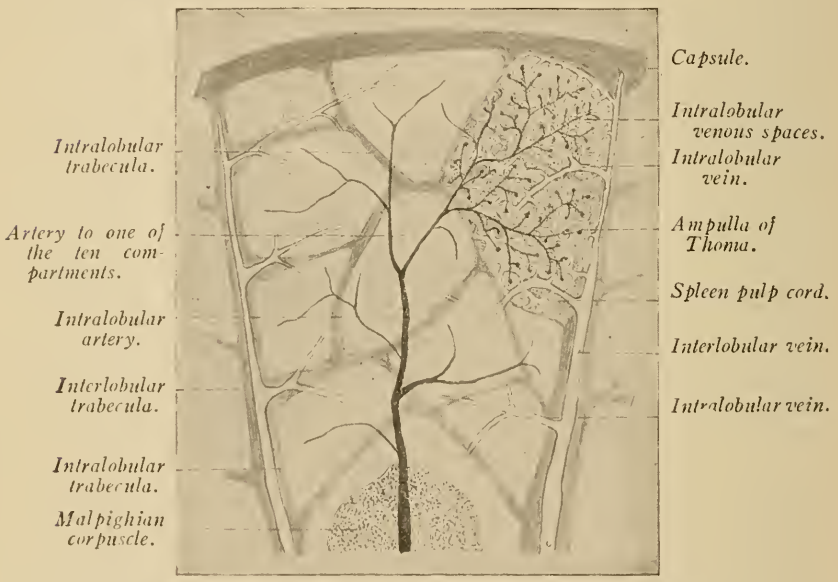


Fig. 98.—Diagram of lobule of the spleen (Mall).

The function of the thymus gland is not known. Since its structure resembles the tissue of a lymph node it is reasonable to suppose that it has a like function. Recently structural changes have been observed in this organ in epileptics, but whether these changes are a cause or a consequence of the disease is not known.

The lymphoid tissue of the spleen no doubt

contributes to the supply of white blood-corpuscles. The broken-down red corpuscles found in this organ have led to the further idea that the spleen is a graveyard for the worn-out red corpuscles of the blood. Leucocytes are supposed to feed upon this detritus and then migrate to the liver, where it is elaborated into the bile pigment of that organ.

Anything that causes an enlargement of the lymph nodes usually causes an enlargement of the spleen. Like these nodes the spleen is capable of enormous distention, due to the abundance of elastic connective-tissue fibers. This is particularly so in typhoid fever, where the spleen has been known to weigh fifteen or twenty pounds.

On account of the rich blood supply an injury to the spleen causes severe hemorrhage, which the pulpy condition of the organ renders difficult to check, as a suture usually does not hold. In such accidents the whole spleen has been removed without fatal results. Extirpation of the spleen is also justified in certain diseases of that organ.

CHAPTER IV.

DIGESTIVE SYSTEM.

The digestive system consists of *alimentary canal* and *accessory digestive glands.*

The Alimentary Canal.—This is a muscular tube extending through the body and measures about thirty feet in length. The following parts will be described:

I. Mouth
II. Pharynx.
III. Esophagus.
IV. Stomach.
V. Small Intestine.
    1. Duodenum.
    2. Jejunum.
    3. Ileum.
IV. Large Intestine.
    1. Vermiform Appendix.
    2. Cecum.
    3. Colon.
        (*a*) Ascending.
        (*b*) Transverse.
        (*c*) Descending.
        (*d*) Sigmoid Flexure.
    4. Rectum.

THE MOUTH.

The mouth is limited by the lips in front, and the cheeks laterally. The arched palate forms its roof

and the tongue is attached to the movable floor, while posteriorly it opens into the pharynx through the *isthmus* or *fauces*. This cavity is lined by a continuous mucous membrane, consisting of stratified mucous epithelium placed on a *tunica propria*. In

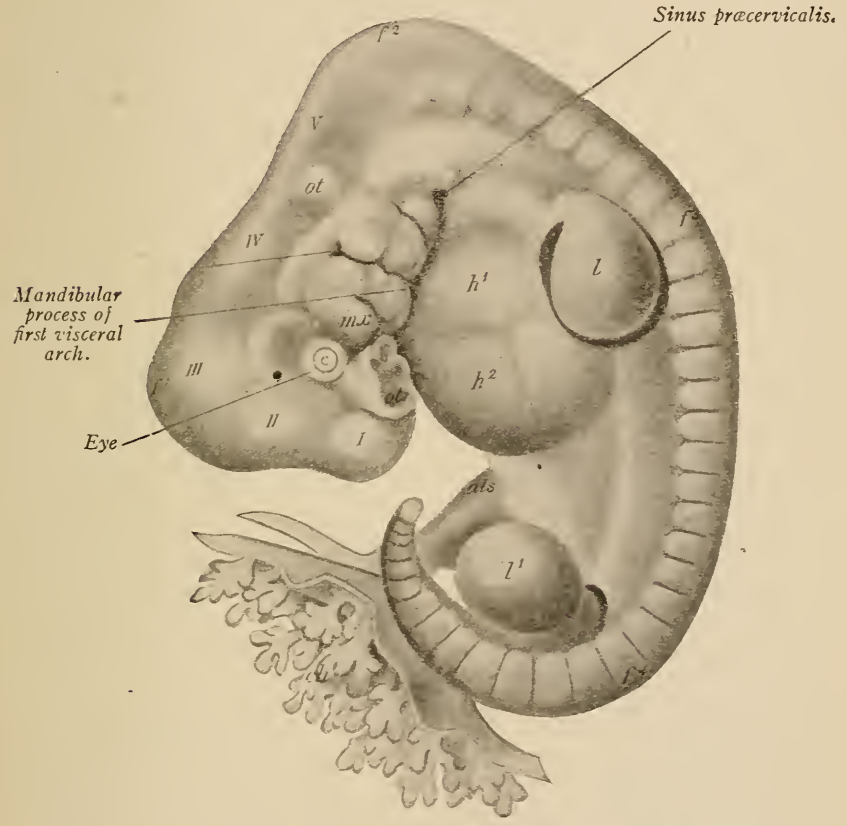


Fig. 99. — Human embryo of about twenty-eight days (His): I–V, brain-vesicles; f^1, f^2, f^3, f^4, cephalic, cervical, dorsal, and lumbar flexures; *ot*, otic vesicle; *ol*, olfactory pit; *mx*, maxillary process; h^1, h^2, heart; *l*, l^1, limbs; *a l s*, allantoic stalk; *c h*, villous chorion.

the submucosa is found connective-tissue elements in which the elastic fibers predominate; also connective-tissue cells, mucous and serous glands, nerves, and nerve endings, blood- and lymph-vessels.

The mucous membrane is continuous with the skin at the outer border of the lips. At this border the horny layer of skin begins, otherwise the skin and this mucous membrane are similar structures.

Morphologically, the mouth cavity is to be regarded as a part of the outside surface of the body, which, embryologically, has been included by the development of neighboring parts. At the time the neural folds are closing dorsally to form the brain and cord there develops a series of paired, ventral, facial pits. These, enumerated from before backwards, are: the lens of the eye, the nasal pit, the mouth, and gill clefts. The tissue between the latter are called *visceral arches*, while that one between the anterior gill cleft and the mouth cavity is the *mandibular arch*. The latter is morphologically analogous to the visceral arches. In man the gill clefts all finally close permanently, but the ectodermal embryonic mouth cavity ultimately unites with the embryonic foregut, thus forming the *fauces* which lead to the pharynx. This final perforation between the mouth cavity and the foregut is paired, in lower forms, which with other embryonic relations confirms the view that the mouth cavity morphologically represents a median fusion of two gill clefts.

During this period of development the forebrain grows ventrally and the mandibular arch grows in the same direction. The space between these structures is the beginning of the mouth and the nose, and is called the *stomodeum*. At this time a rounded elevation, from the base of the mandibular arch, grows forward along the base of the forebrain. This growth

forms *part* of the maxillary arch, and finally most of the upper jaw. In this manner the stomodeum

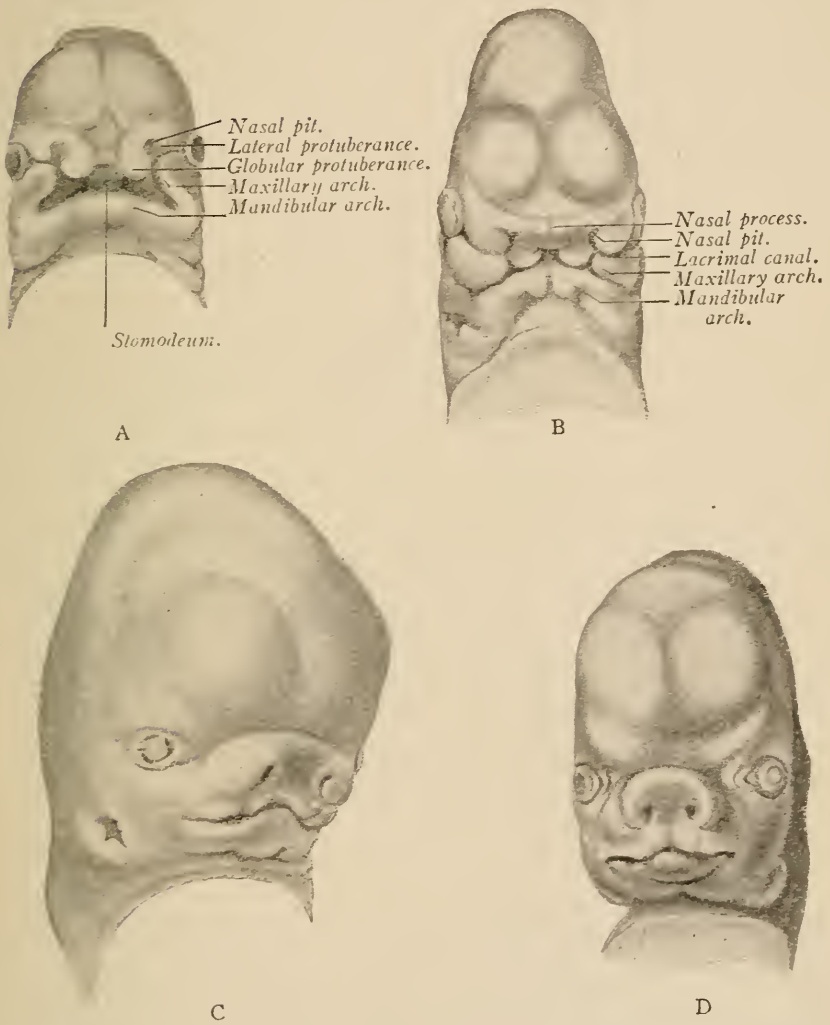


Fig. 100.— Development of the face of the human embryo (His): A, Embryo of about twenty-nine days; B, embryo of about thirty-four days; C, embryo of about the eighth week; D, embryo at end of the second month.

becomes divided into an olfactory region and the mouth cavity proper. The stomodeum at this stage

is a deep pentagonal cavity. Its lower boundary is formed by the mandibular arch, while laterally are to be found the maxillary processes of each side. Its upper boundary is formed by an unpaired growth called the *nasofrontal* or *nasal process* (Fig. 100.) Situated on each side of the nasal process are the *nasal pits*. Each pit divides the nasofrontal process into a lateral external portion called the *lateral frontal protuberance*, which forms the outer boundary

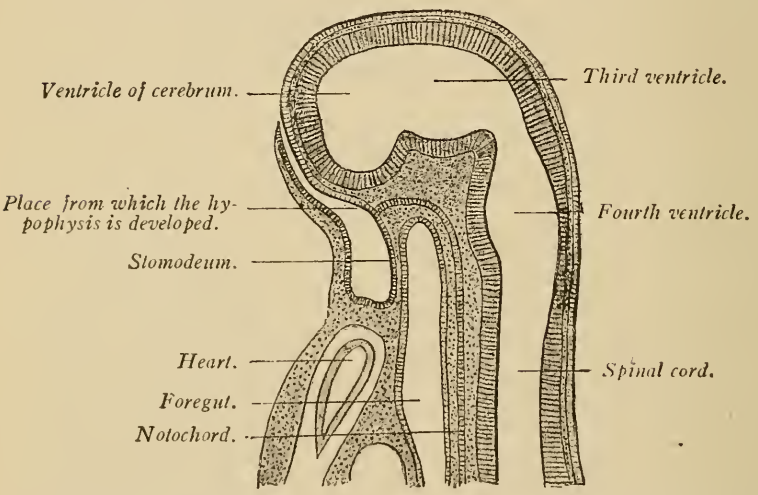


Fig. 101.—Median section through the head of an embryo rabbit 6 mm. long (after Mihalkovics)

of each nasal pit, and a median or central portion called the *globular protuberance*, which constitutes the inner boundary of each pit. The two lateral or side protuberances grow around the olfactory pits and form the alæ of the nose, while the two central portions develop into the intermaxillary bone containing the incisor teeth and the center of the lip.

By studying the text figures a correct idea of these

relations is readily obtained. It will be seen that the line of contact between each lateral protuberance and maxillary process forms a groove, the *naso-optic furrow* or *lacrimal groove*, which later closes to form the lacrimal canal. The line of contact between each globular protuberance and the maxillary process is less close, and places each nasal pit in wide communication with the mouth. A failure of union in the latter case causes the deformity of harelip,

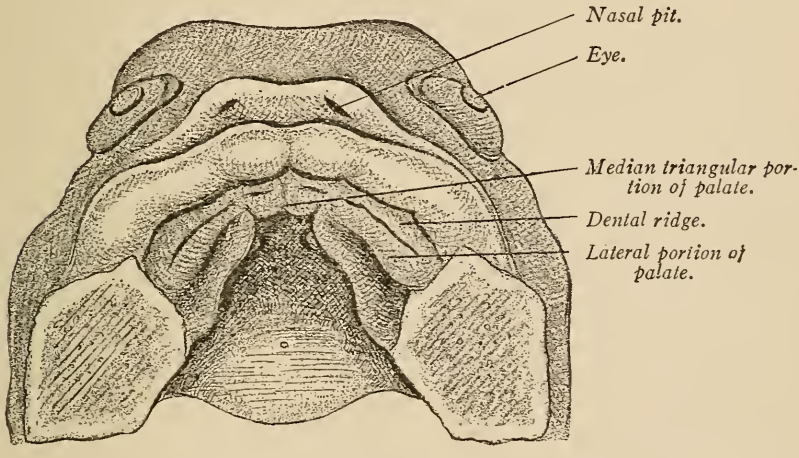


Fig. 102.—Roof of the oral cavity of a human embryo with the fundaments of the palatal processes (after His).

which may be double or single, depending on whether both or only one side is involved.

About the fortieth day, in the human embryo, the maxillary processes have grown so far toward the median plane that they have met and united with the lateral and also the median protuberances of the nasofrontal process. The nasal pits are thus separated externally from the oral fossa. With this union the arch of the upper jaw is complete, but the

inclosed space is in one chamber, there being no separation between the mouth and nose cavities. The formation of a *palate*, however, effects a separation between the two. The rudiments of the palate appear as shelf-like projections from the inner or oral surface of the upper jaw. A triangular piece grows backward from the globular protuberance of the nasofrontal process, which ultimately unites with horizontal or palatal plates from the maxillary arch. In the eighth week of embryonic life, union of the palatal plates begins at their anterior extremities and proceeds backward. A deficiency in the union constitutes the deformity of *cleft palate*. Cleft palate is therefore, embryologically, a later development than harelip. Either may occur without the other, but they are usually found together. The cleft of the palate usually turns to one side, passing out between the cuspid and lateral incisor teeth. A double cleft palate is Y-shaped, the center piece in front containing the incisors, and representing the anterior triangular piece of the rudimentary palate, this piece having failed to unite with the lateral palatine plates. This deficiency may involve the hard or the soft palate, or it may affect both, and even produce a cleft or bifid uvula.

The completion of the palate definitely separates the nasal chambers from the mouth, the only communication between the two being through the posterior nares. The permanent limitations of the mouth are thus established from a cavity that develops primarily as an ectodermal invagination. The ectoderm invests not only the mouth proper,

but clothes at least the anterior portion of the adult pharynx. The tongue, however, is invested with entoderm epithelium and so are the Eustachian tubes.

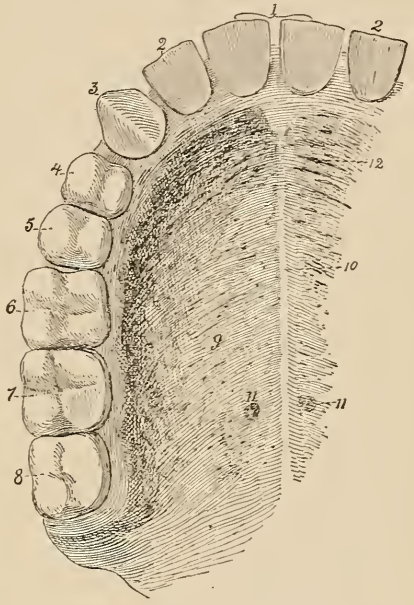


Fig. 103.—The palate and superior dental arch (right side): 1, Median incisors; 2, lateral incisors; 3, canine; 4, first bicuspid; 5, second bicuspid; 6, first molar; 7, second molar; 8, wisdom-tooth; 9, mucous membrane of the hard palate continuous behind with that of the soft palate; 10, the anteroposterior raphe of palate; 11, pits on each side of the raphe perforated with the orifices of glands; 12, anterior rugosities of the mucous membrane (after Testut).

TEETH.

Morphologically, teeth are appendages of the skin, and are to be compared with such structures as hair and nails. They are thus a part of the exoskeleton and their relation to the bones or the endoskeleton is entirely a secondary process, for the purpose of strength and support. In many of the fishes the mouth generally is lined by simple cone-shaped teeth that serve the purpose of seizing and holding the animal's prey. In man the additional function of masticating the food has greatly modified the form and structure of teeth.

Dentition.—There are twenty *deciduous* or *temporary* teeth that erupt between the ages of six months and two and one-half years. In each jaw these are,—incisors 4, cuspids 2, molars 4, the dental

CHRONOLOGY OF THE DENTAL FOLLICLE IN MAN (Legros and Magitot).

	Designation of the Follicles.	Place of Origin of the Epithelial Cord.	Period at which the Enamel-Organ First Appears.	Period at which the Dental Bulb Appears.	Time of the Appearance of the Follicular Wall.	Closing of the Follicle and Rupture of the Cord.	Periods at which the Dentine-cap First Appears.	Periods at which the Teeth are Erupted.	Periods at which the Teeth are Normally Shed.
Temporary dentition.	Inf. cent. incis.	. .	. .	. .	. .	. .	. .	6th month.	7th year.
	Sup. cent. incis.	. .	. .	. .	. .	. .	. .	10th month.	7½ years.
	Inf. lat. incis.	. .	. .	. .	. .	. .	16th week.	16th month.	8th year.
	Sup. lat. incis.	. .	. .	. .	. .	. .	. .	20th month.	
	Inf. cuspids.								
	Sup. cuspids.	Epithelial lamina.	From 7th to 8th week.	9th week.	10th week.	Beginning of the 4th month.	. .	30th to the 32d month.	12th year.
	1st inf. molars	. .	. .	. .	. .	. .	. .		
	1st sup. molars	. .	. .	. .	. .	. .	. .	24th month.	10th year.
	2d inf. molars	. .	. .	. .	. .	. .	17th week.	26th month.	10½ years.
	2d sup. molars	.	. .	. .	. .	. .	. .	28th month.	11th year.
								30th month.	11½ years.

Permanent dentition.	Inf. cent. incis.	Cord of the corresponding temporary teeth.	..	..	..	..	..	7th year.
	Sup. cent. incis.		..	..	..	..	..	
	Inf. lat. incis.		..	..	..	..	..	8½ years.
	Sup. lat. incis.		..	..	..	..	..	
	Inf. cuspids.		About the 16th week.	20th week.	21st week.	9th month.	1st month after birth.	11 to 12 years.
	Sup. cuspids.							
	1st inf. bicusp.	Cord of the corresponding temporary molars.	..	..	..	..	..	9 to 10 years.
	1st sup. bicusp.		..	..	..	..	..	
	2d inf. bicusp.		..	..	..	..	..	11th year.
	2d sup. bicusp.		..	..	..	..	..	
	1st inf. molars	Epithelial lamina.	15th week.	17th week.	18th week.	20th week.	6th month of fetal life.	From 5 to 6 years.
	1st sup. molars							
	2d inf. molars	Cord of the 1st permanent molars.	3d mo. after birth.	1st year.	1st year.	1st year.	3d year.	From 12 to 13 years.
	2d sup. molars							
	3d inf. molars	Cord of the 2d permanent molars.	3d year.	After the 6th year.	After the 6th year.	After the 6th year.	12th year.	From 18 to 25 years.
	3d sup. molars							

formula for one side being,—I.$\frac{2}{2}$ C.$\frac{1}{1}$ M.$\frac{2}{2}$ = 10. The second set, or *permanent* teeth, number thirty-two

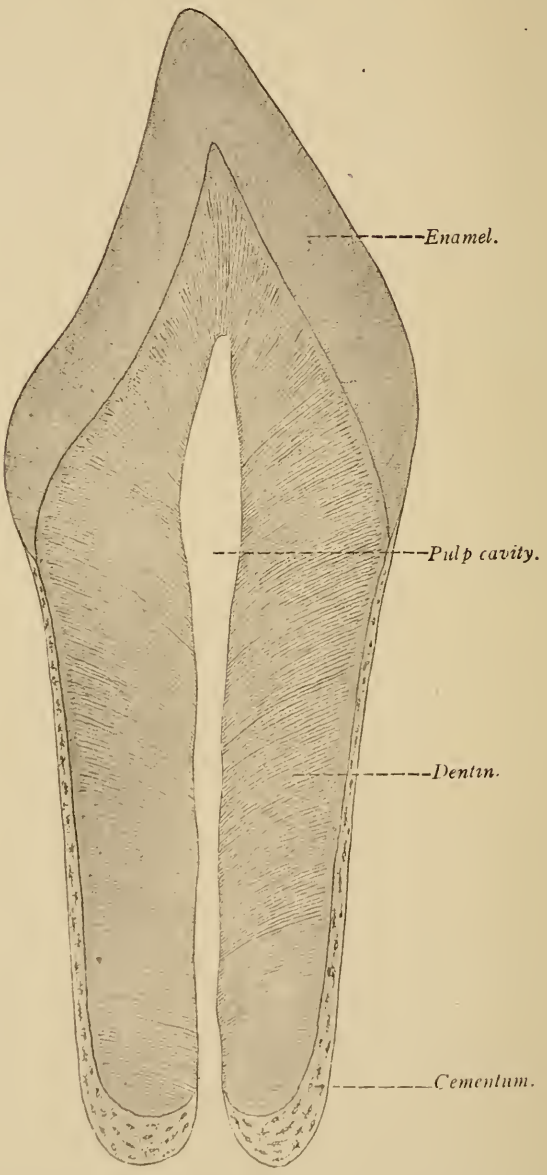


Fig. 104.—Scheme of a longitudinal section through a human tooth. In the enamel are seen the "lines of Retzius" (Böhm and Davidoff).

PLATE II.

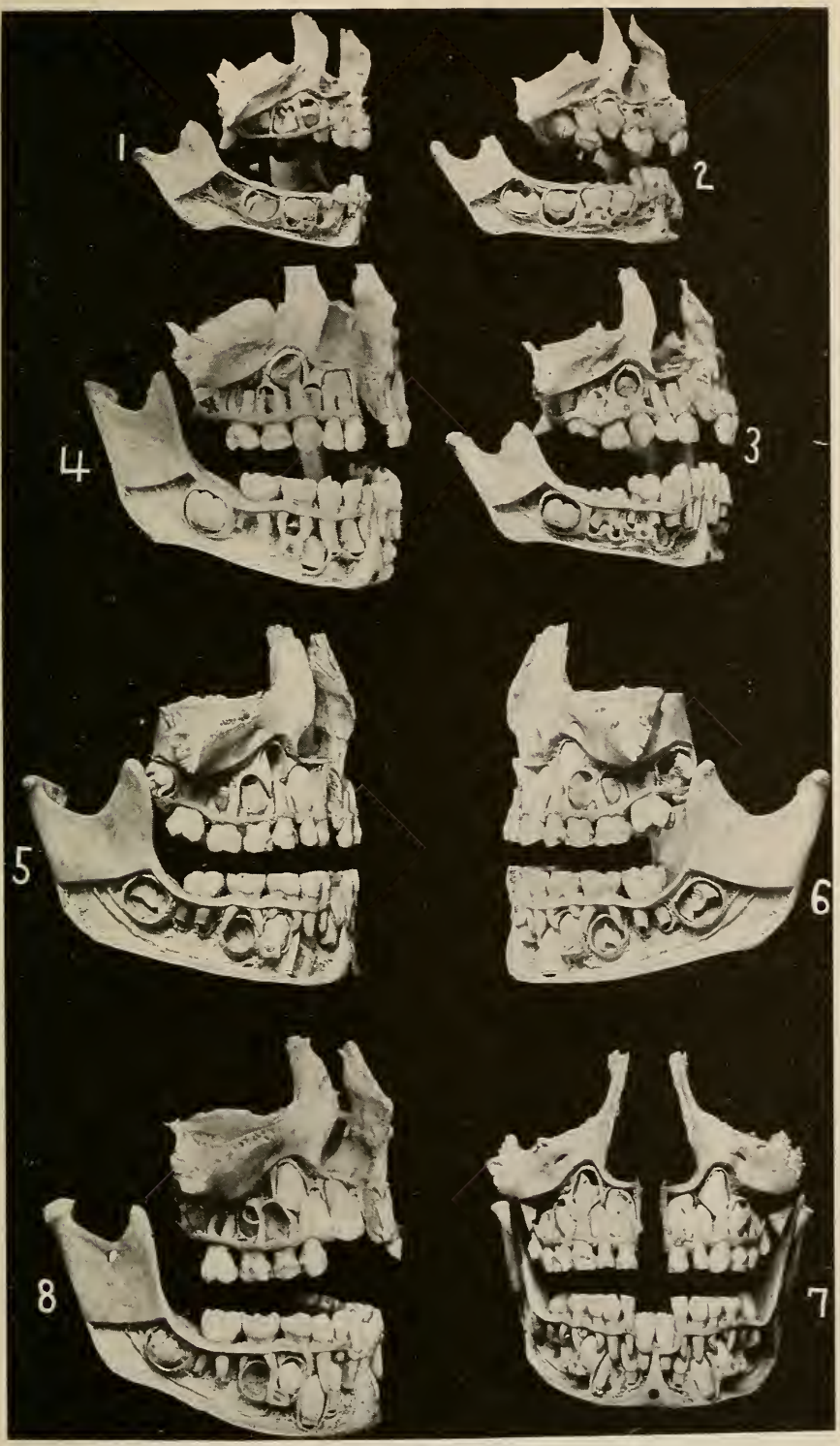
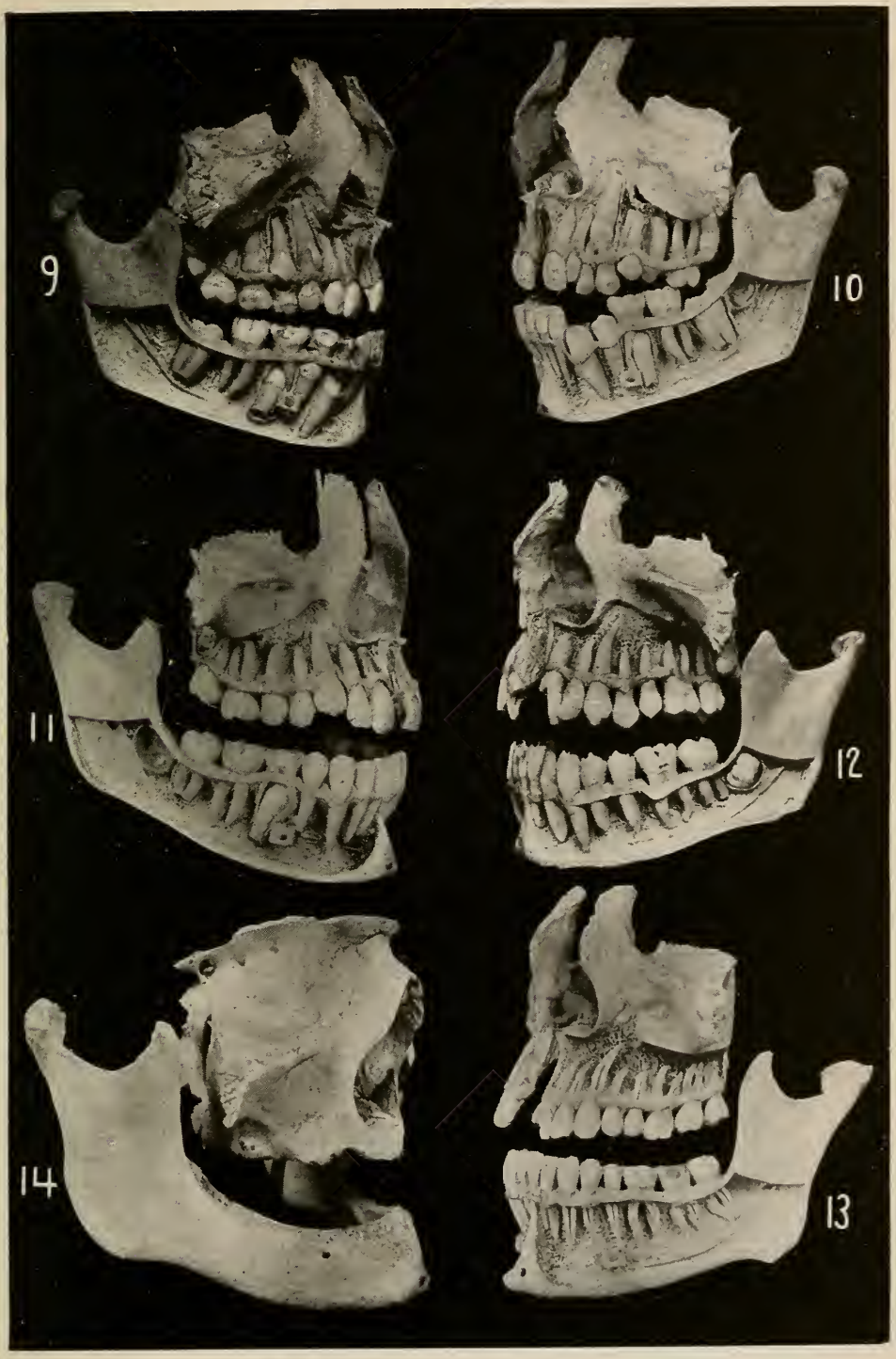


PLATE III.



and in each jaw are divided into,—incisors 4, cuspids 2, bicuspids 4, molars, 6, the dental formula for one side being,—I.$\frac{2}{2}$ C.$\frac{1}{1}$ B.$\frac{2}{2}$ M.$\frac{3}{3}$ = 16.

Structure of Teeth.—The parts of a tooth are crown, neck, roots and pulp. Its calcareous wall consists of enamel, dentin, and cementum.

Enamel.—The enamel is the hardest tissue in the body and covers the exposed portion, or crown, of the teeth. Its function is to mechanically protect the tooth. This enamel is derived from the ectoderm, while all bone tissues are products of the mesoderm. Bone, if injured, may regenerate and repair the defect. Enamel does not regenerate if injured, the defect being permanent, as the formative enamel tissue disappears before the eruption of the tooth. Chemically, it is composed of phosphates and carbonates of calcium and magnesium, a small amount of fluorides, water, and perhaps a very small amount of organic material. In consequence of the latter, enamel, unlike bone, is soluble in acids, leaving scarcely any residue.

Enamel is composed of two structural elements,—(*a*) *enamel rods* or *prisms* (also called fibers), and (*b*) *interprismatic* or *cement substance*, both of which are calcified. These elements have different properties, both chemical and physical. The interprismatic substance is more readily acted upon by acids, and it is therefore possible to etch enamel sections and produce a disassociation of the enamel rods. The interprismatic substance is not so strong as the rods, and in splitting or breaking the enamel the tissue usually separates along the cement lines; that is,

these lines form paths of least resistance, a fact taken advantage of in operative dentistry.

According to Noyes ("Dental Histology"), "the enamel rods, or prisms, are long, slender prismatic rods or fibers, five- or six-sided, pointed at both ends, and alternately expanded and constricted throughout their length. They are from 3.4 to 4.5 microns in diameter, some of them apparently reaching the entire distance from the surface of the dentin to the surface of the enamel, but, as the diameter of the rods is the same at their outer and inner ends, and as the crown surface is much greater than the surface of dentin covered by enamel, there are many rods that do not extend through the entire thickness. These short rods end in tapering points between the converging rods, which extend the entire distance. To express this in terms of development, as the formation of enamel begins at the surface of the dentin, the increasing area of crown surface requires more ameloblasts, and as new ameloblasts take their places in the layer the formation of new enamel rods begins between the rods which were previously forming. These short rods are most numerous over the marginal ridges and the points of the cusps."

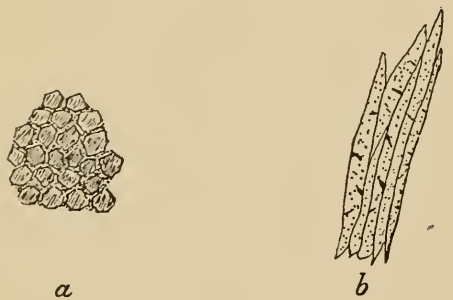


Fig. 105.—*a*, Enamel rods in cross section; *b*, Enamel rods, longitudinal view.

The rods are not perfectly smooth and even, but show alternately expansions and constrictions.

They are so arranged that the expansion of adjacent rods lie opposite each other; that is, the expansions do not interlock with the constrictions. The cement substance, therefore, has a reciprocal arrangement.

Sections ground parallel to the rods show, therefore, dark and light lines, described as the *striations of the enamel*, which are caused by the difference in the refracting power of the prismatic and interprismatic substances. In a ground section across the rods, the tissue presents a mosaic pattern, which becomes more distinct if treated with acid.

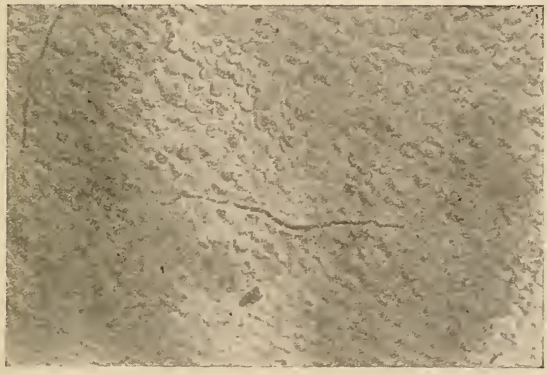


Fig. 106.—Transverse section of enamel (Noyes).

Lines of Retzius.—These lines or stratification bands begin at the tip of the dentin cusps and sweep around in larger and larger zones. They thus pass obliquely through the enamel and record the growth of the crown, as each line was at one time the surface of the enamel. They are to be regarded as traces of the strata caused by the periodic deposition of lime salts.

According to Noyes, "the appearance of striation is the record in the fully formed tissue of the manner

of growth, each dark stripe or expansion in a rod representing a globule of calcified material. The ameloblasts build up the rods by the addition of globule after globule, surrounding them with a cementing substance and completing the calcification of both. In this sense the striation of the enamel may be said to record the growth of the individual rods."

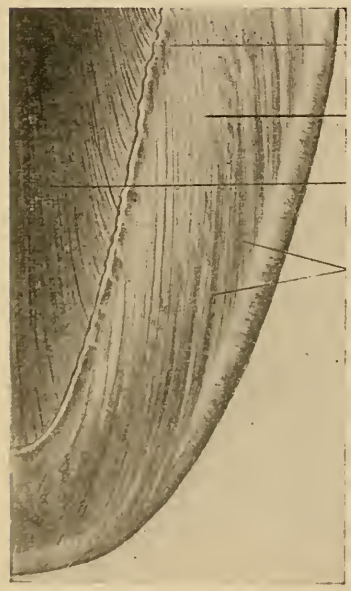


Fig. 107.—Tip of an incisor, showing lines of stratification of the enamel (Noyes).

Direction of the Enamel Rods.—Upon the axial surface the rods are usually straight and parallel with each other, but upon the occlusal surface they change their direction by a series of symmetrical curves, and often become much twisted and wound around each other, particularly the inner ends. In operative dentistry it is found that the enamel upon the axial surface cleaves readily while the gnarled portion upon the occlusal surface tends to break away in chunks.

Fig. 110 shows the general plan of the arrangement of the enamel rods in the formation of the crown. In the gingival half of the middle third the rods are horizontal. Their inclination, from this horizontal direction, gradually increases toward the

root and toward the occlusal surface, so that at the apices of the latter surface the rods are placed vertical to a horizontal plane. Because of this plan Noyes divides all cavities, in dental work, into two classes:

"1.—Those in which the enamel rods are in-

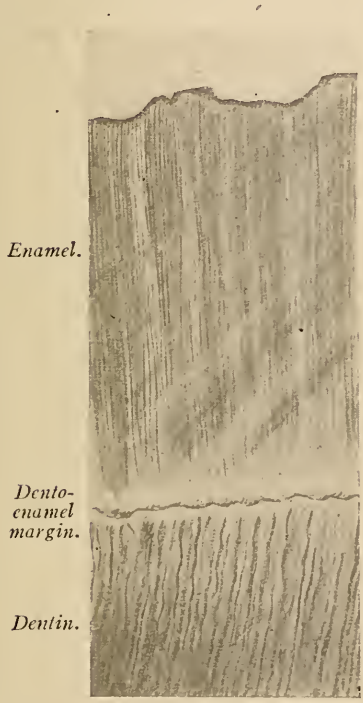


Fig. 108. — Straight enamel, showing dento-enamel junction (Noyes).

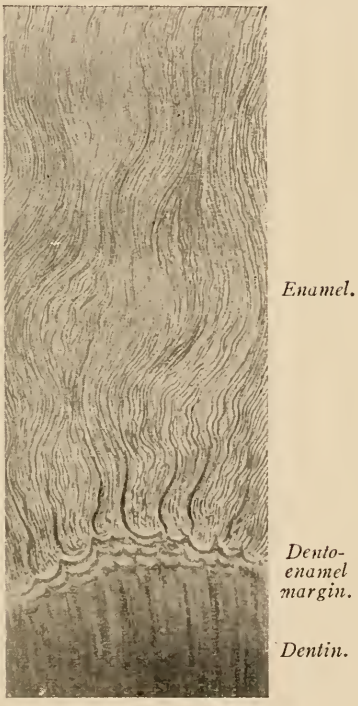


Fig. 109. — Gnarled enamel, showing dento-enamel junction (Noyes).

clined toward the cavity, characteristic of the occlusal surfaces.

"2.—Those in which the enamel rods are inclined away from the cavity, characteristic of axial surfaces" (Fig. 111).

In preparing cavities on the axial surfaces the

lateral walls should be beveled, as shown in the above figure. The historic requirements for strength in enamel walls are:

1. The enamel must be supported upon sound dentin.

2. The rods which form the cavo-surface angle must run uninterruptedly to the dentin.

3. They must be supported by short rods, with

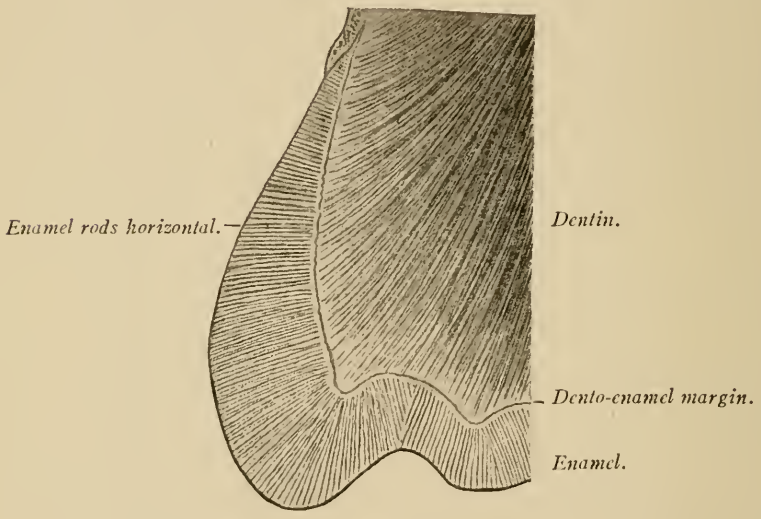


Fig. 110.—Drawing, showing the direction of the rods over the mesial marginal ridge of a bicuspid (Noyes).

their inner ends resting on the dentin and their outer ends abutting upon the cavity wall, where they will be covered by the filling material.

4. That the cavo-surface angle be cut in such a way as not to expose the ends of the rods to fracture in condensing the filling material against them.

"The first step in the preparation of an enamel wall is to determine the direction of the enamel rods by cleavage with a chisel or hatchet. Then the wall

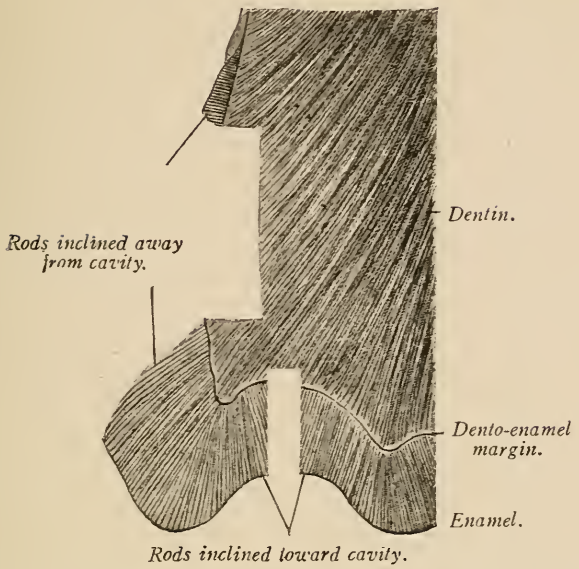


Fig. 111.—Illustrating the two classes of cavities (Noyes).

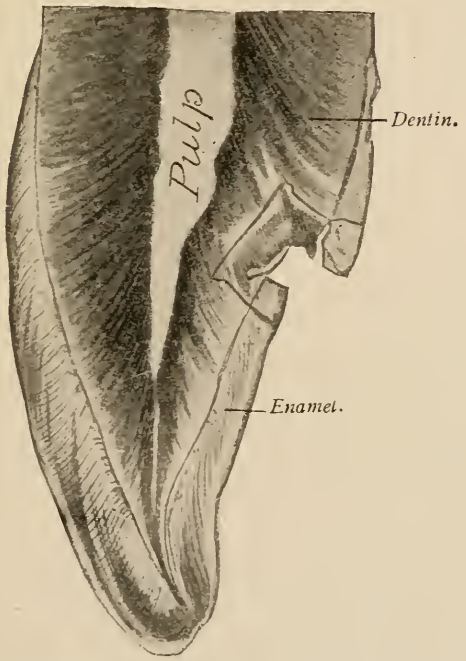


Fig. 112.—Labio-lingual section of superior lateral incisor, showing a pit cavity (Noyes).

must be smoothed or trimmed by a shaving motion of the chisel, increasing the inclination of the wall slightly. This is done so as to be sure and reach the rod directions and remove the portions of the tissue that has been splintered by the cleavage. Then the cavo-surface may or may not be trimmed, as the position demands" (Fig. 111, Noyes).

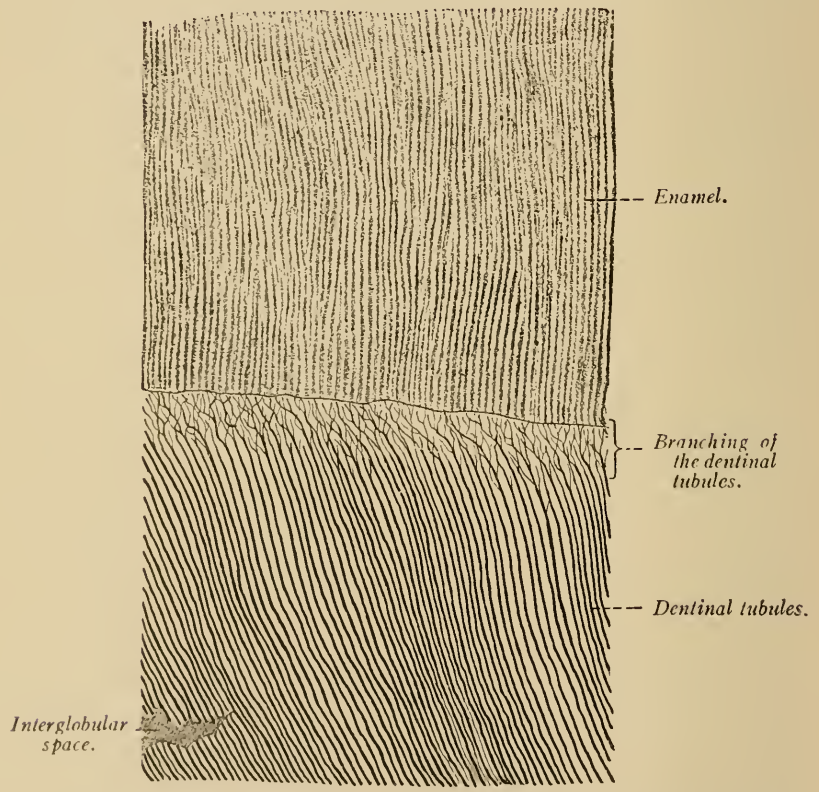


Fig. 113.—A portion of a ground tooth from man, showing enamel and dentin (Böhm and Davidoff).

Grooves, fissures, pits and developmental lines are points of weakness and in operative work cavities must be excavated so as to establish a strong margin, histologically, against which to pack the

filling. The arrangement of the enamel rods must therefore be constantly borne in mind in the operative repair of teeth.

Dentin.—The dentin is the second layer of teeth, and not only makes up the mass of a tooth but determines its form; that is, the number of cusps and roots is moulded by the developmental process of the dentin. Its histologic form has much to do with the penetration of caries.

Dentin, like bone, develops from the mesoderm, and consists of an organic, formative matrix impregnated with about 72 per cent. of inorganic salts. On boiling it yields gelatin. Minute canals of dentinal tubules radiate from the central cavity of the tooth, which contains the formative organ or pulp. These tubules are from 1.1 to 2.3 microns in diameter and are separated from each other by a *dentinal matrix* of about 10 microns in diameter. In the crown the tubules branch but little, excepting close to the enamel where they anastomose freely. In the crown they radiate in sweeping curves so as to open at right angles on the dentinal surface. This produces "s" or "f"-shaped curves known as *primary curves*. They also present many wavy curves known as *secondary curves*, which is really the result of an open spiral course taken by the tubules. In the body of the dentin a few small branches are given off at acute angles, but near the enamel junction the tubules fork and branch freely, forming an anastomosis that facilitates in the spreading of caries just beneath the enamel, the micro-organisms diffusing sideways and then penetrating the dentin in the direction of the tubes.

In the root the tubules radiate directly to the cementum, showing only the primary curves. Many fine branches pass in all directions from tubule to tubule. The dentin next to the cementum contains many small irregular spaces that connect with the dentinal tubules. They present a granular appearance in ground sections, and are therefore called the *granular layer of Tomes*. These spaces are filled by the enlarged ends of the dentinal fibrils, which are *cell processes* of the *odontoblasts*, while the fibrils also fill the dentinal tubules. The layer of Tomes may sometimes be found beneath the enamel, but is never well marked.

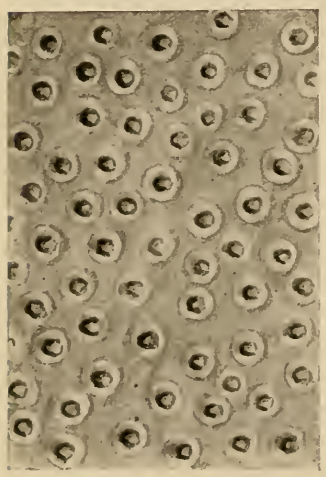


Fig. 114.—Section of dentin at right angles to the tubules (Noyes).

The dento-enamel junction presents rounded projections. This scalloped appearance has given rise to the view that certain dentinal tubules pass for a short distance into the enamel. In ground sections, irregularly branched dentinal spaces are often found at a uniform depth from the surface. These are the *interglobular spaces of Czermak* and represent areas of imperfectly developed dentin. Lastly, the *sheaths of Neumann* represent the inner wall of the dentinal tubules, and may be regarded as differentiated and more resistant ground substance.

The formation of dentin continues for an indef-

inite period after the eruption of a tooth. The process is one of apposition, thickening the dentin at the expense of the pulp. Finally this growth ceases. Irritation of the pulp, or the pulp of some tooth on the same side, may lead to the formation of *secondary dentin.* The latter is an imperfect structure. The tubules are smaller and less numerous, while the matrix is less compact and shows a deficiency of

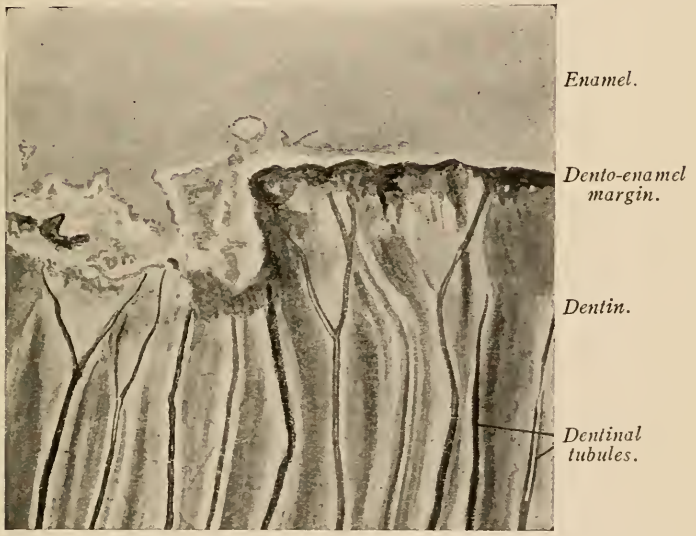


Fig. 115.—Section of dentin in the crown cut in length of the tubules (Noyes).

inorganic salts. Several deposits of secondary dentin may thus be produced.

The Pulp.—The pulp occupies the center of the tooth. It consists of connective-tissue cells, connective-tissue fibrils, a semifluid interfibrillar ground substance, nerve plexus largely non-medullated, blood and lymph vessels. We may recognize three kinds or layers of cells, the most important being the

odontoblasts, forming the outer surface of the pulp next to the dentin.

1. The *odontoblasts* form a continuous layer over the entire pulp surface, being everywhere in contact with the dentin. This layer has been called the

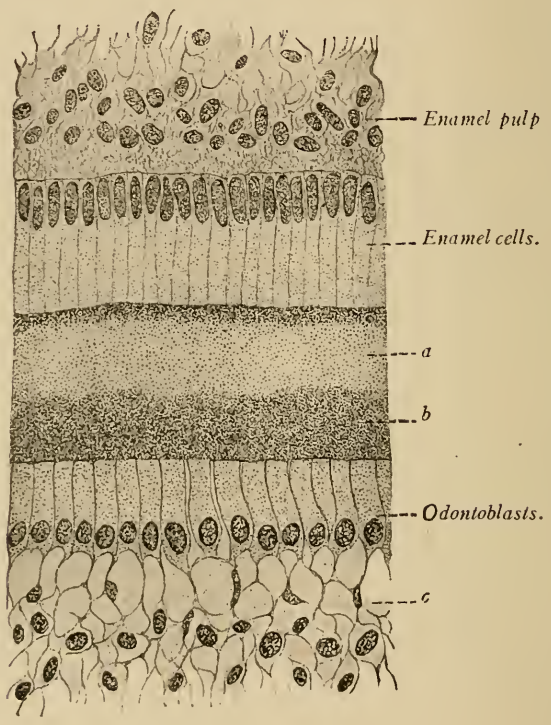


Fig. 116.—A portion of a cross section through a developing tooth (Böhm and Davidoff). The dentin is formed, but has become homogeneous from calcification. Bleu de Lyon differentiates it into zones (*a* and *b*). At *c* is seen the intimate relationship of the odontoblasts to the tissue of the dental pulp.

membrane eboris or the "membrane of ivory." The odontoblasts are mesoderm cells, columnar, sometimes club-shaped, with basal nuclei and three kinds of processes. (1) Each cell has one to three long, slender, protoplasmic processes projecting into

the dentinal tubules, and extending through the tubule to the outer surface of the dentin, where they completely fill the granular spaces already described as the granular layer of Tomes. It is generally believed that these processes may transmit impressions to the sensory nerves of the pulp. (2) Each odontoblast shows lateral processes, minute but blunt, that interlock with like processes from adjacent cells. (3) Usually a single process projects from the basal end into the pulp.

The odontoblasts are dentin-forming cells and superintend the formation and calcification of primary and secondary dentin.

2. The *layer of Weil* represents a layer of connective-tissue cells forming a thin zone just beneath the odontoblasts. In thin sections this appears as a thin layer about half as thick as that of the odontoblasts.

3. Underneath the layer of Weil the connective-tissue cells are numerous and closely packed. Toward the center of the pulp they become loosely but uniformly scattered. The cells are small, have a single deep-staining nucleus, and the cytoplasm stretching out into slender processes in many directions, forming stellate cells; or in two directions to form spindle cells.

The connective-tissue fibrils of the pulp are similar to those of white fibrous connective tissue, sometimes resembling the reticular variety. The vascular condition of the pulp makes it an organ of nourishment for the dentin as well as the mature tooth.

Cementum.—The cementum covers the dentin in

the root portion of a tooth. At the gingival margin it slightly overlaps the enamel. Near this margin it forms a thin layer, but becomes thicker toward the apex of the root and between the roots of the bicuspids and molars. The cementum consists of parallel lamellæ of bone tissue that contain no Haversian canals. Small blood-vessels from the investing peridental membrane penetrate the lamellæ, while other small vessels from the pulp pass through

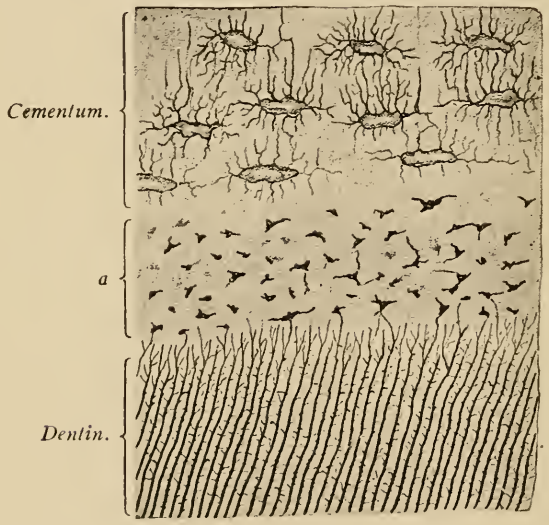


Fig. 117.—Cross section of human tooth, showing cement and dentin. At *a* are seen small interglobular spaces (Tomes' granular layer).

the cementum in the opposite direction. Fibers from the investing peridental membrane find attachment in the cementum. These fibers resemble the fibers of Sharpey in bone. The cementum, therefore, furnishes a medium of attachment by which the tooth is held in position.

Cementum is constantly being produced by the apposition of new surface layers. In newly erupted

teeth the cementum is thin and in teeth of old persons the cementum is thick. This continuous growth is necessary in order to establish attachment for new fibers of the peridental membrane and to conform to the natural growth of the jaw.

Between the lamellæ, particularly in the apical portion of the root where the cementum is thick, numerous lacunæ are present, resembling those of bone. Canaliculi radiate from these lacunæ with less regularity, however, than in the case of bone. They may be confined to one side of a lacuna, usually the side toward the surface.

Local thickenings of the cementum, called hypertrophies, are common. These enlargements involve one or more of the lamellæ and were formerly called exostoses, or cementostoses.

Peridental Membrane.—This is an organic tissue that surrounds the root of teeth and occupies the space between the cementum and the bony wall of the *alveoli*. Its chief function is to anchor a tooth to the jaw and give support to the gingivus. Its chief constituent is white connective-tissue fibers interspersed with a variety of cells, blood-vessels, lymphatics and nerves.

The *fibrous tissue* may be divided into two classes: coarse, radiating fibers that form the principal bulk and perform the principal function of anchorage, and a secondary fine variety that interlace with these and unite largely with the anastomosing blood-vessels of the tissue. The principal fibers connect, on the one hand, with the cementum which they enter in bundles to form the fibers of Sharpey, and on the other

hand they unite with the periosteum of the bony alvoli and the subepithelial tissue of the gum. From the upper portion of the cementum these fibers pass horizontally, some of them directly to connect with the cementum of adjacent teeth and others to mingle with the connective tissue of the adjacent mucous membrane, thus giving a firm support to the

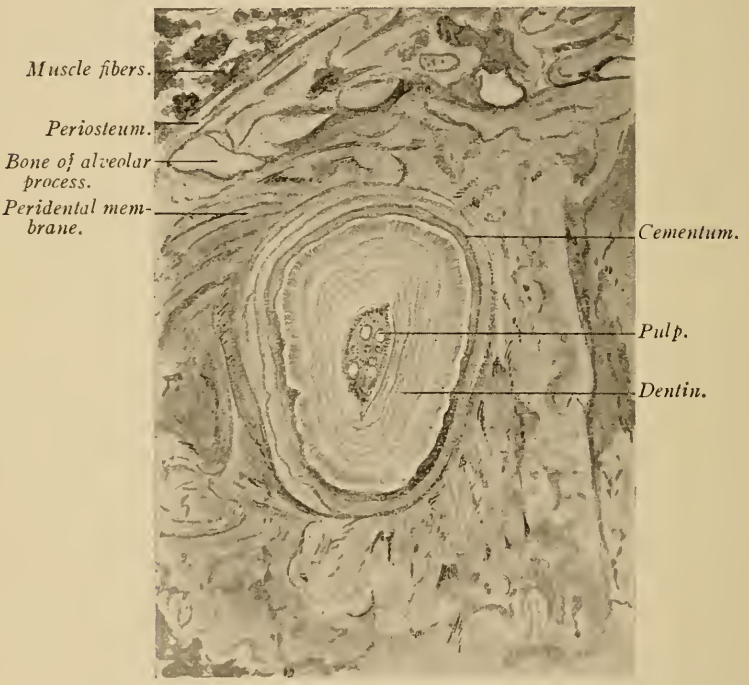


Fig. 118.—Transverse section of peridental membrane in alveolar portion (Noyes).

gingivus, a condition which becomes of primary importance in the mastication of food. The fibrous mat of the gum is usually greater on the lingual side, where food is brought against the gingivus with considerable force. If a crown band is extended too far, or if deposits accumulate as in case of uncared-for

teeth, these supporting fibers will be cut off and the gingivus drops down and no longer fills the interproximal space.

In the alveolar portion the principal fibers not only spread out and radiate like a fan, but are inclined downward from their attachment in the cementum to their anchorage in the bony wall of the alveolus. Some of these fibers are tangential to the cementum and thus support the tooth against a rotary strain. The principal fibers thus perform a physical function and firmly bind the tooth to the adjacent hard and soft tissues. At the alveolar border and at the apex of the root they are so arranged as to support the tooth against lateral strain, while in the rest of the alveolar portion the tangential fibers are particularly numerous and support the tooth against any rotary force which may result from the mastication of food. At the gingivus line the fibers blend with the submucosa and bind the gum closely to the neck of the tooth. At the apex of the root the secondary loose variety becomes continuous with the connective tissue of the tooth pulp.

The *cellular elements* of the peridental membrane are the *fibroblasts*, *cementoblasts*, *osteoblasts*, *osteoclasts*, and *epithelial cells*, which have been called the glands of the peridental membrane. All these cells are interposed between the bundles of supporting fibers already described.

1. The *fibroblasts* are spindle-shaped connective-tissue cells arranged in radiating rows between the fibers. They are numerous in young teeth and

the root. They produce the cementum and therefore resemble the osteoblasts of bone. They have a single deep-staining nucleus and irregular processes that fit around and between the fibers and also extend into the cementum. A cementoblast may become enclosed in the cementum and thus form a lacuna which it completely fills, thus making a

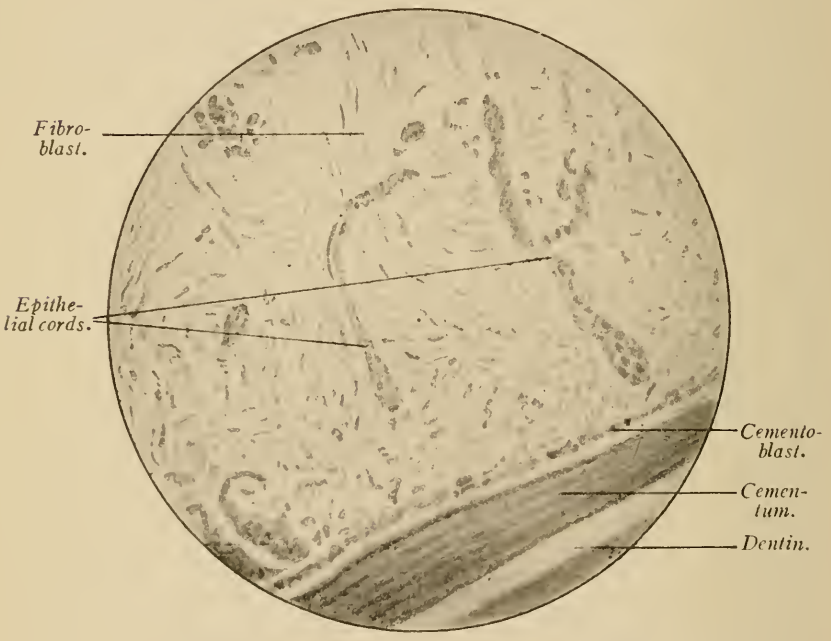


Fig. 119.—Peridental membrane next to the cementum highly magnified (Noyes).

relatively few in old teeth. The single nucleus stains deeply, being rich in chromatin. The cells are small and, as their name implies, their function is the production of fibers that give support to the tooth.

2. The *cementoblasts* are flat irregular cells that fit in and adjust themselves between the fibers so as to form a single layer everywhere over the surface of

cement corpuscle analogous to a bone corpuscle. Such an inclusion is the exception in the life history of these cells.

3. The *osteoblasts* are also connective-tissue cells, but cover the bony wall of the alveoli. They lie between the fibers and their function is the production of bone which anchors the supporting fibers to the alveolar wall. These cells are analogous to the osteoblasts of bone.

4. The *osteoclasts* are large, bone-destroying, multinucleated cells that are often called giant cells. They may also act upon and absorb the cementum and dentin. They are not constantly present in the peridental membrane but appear whenever calcified tissue is to be destroyed. They apply themselves to the surface to be absorbed and by their physiological action excavate cavities in which they lie, known as *Howship's lacunæ.* The latter may later fill in with new cementum or bone, thus leaving a permanent record of the process of absorption and repair. The absorption of the roots of deciduous teeth results from the physiological action of the osteoclasts. If for any cause, such as bacterial invasion, the osteoclasts fail to appear, the root of the deciduous tooth does not absorb but remains as a permanent obstruction to the developing new tooth.

5. *Epithelial cells*, believed by some to be remains of the enamel organ, envelop the surface of the roots and are found in both young and old teeth. Their function is not known. They appear as cords of epithelial cells that anastomose freely to form an enveloping network, which nowhere seems to unite

with the epithelium of the mucous membrane of the mouth. The structure of some of these cords resembles that of tubular glands, and Dr. Black has suggested that their function may be a glandular one. They not infrequently enter into the pathological conditions of the peridental membrane.

Blood Supply.—Usually several small blood-vessels enter the foramina at the apex of the root and pass directly to the pulp. Upon reaching the pulp these vessels anastomose freely, forming an extensive blood plexus. A capillary plexus with narrow meshes has been described between the layer of odontoblasts and the dentin, but does not penetrate the latter. Both arteries and veins have very thin walls and may be easily ruptured. The pulp therefore bleeds very easily when exposed. No accompanying lymphatics have been described.

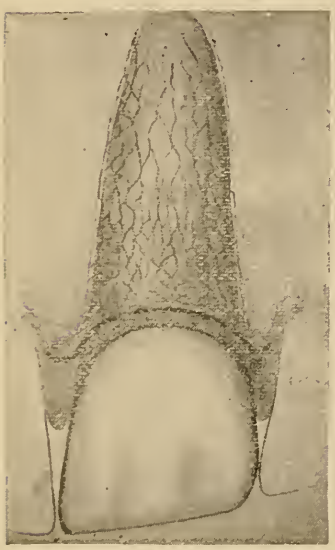


Fig. 120.—Showing the arrangement of epithelial cords or glands of the peridental membrane around the root of a central incisor (diagram by Dr. Black).

The peridental membrane, being a connective-tissue layer, has a very rich blood supply. Vessels enter the membrane near the apex of the root, accompanying the nerve at that place; small arterioles penetrate laterally from the Haversian canals of the alveolar wall, and a third supply is derived from the mucous membrane of the gum,

vessels passing over the border of the alveolar processes. This vascular condition is important, both in health and disease.

Nerve Supply.—The tooth pulp is supplied with nerve fibers from the fifth cranial nerve. Medullated dendrites of sensory neurons enter the pulp cavity through the apical foramen of the root. All of them lose the medullary sheath, but do so at variable distances in the pulp. The varicose den-

Fig. 121.—Nerve termination in the pulp of a rabbit's molar, stained in methylene-blue (*intra vitam*): *a*, Odontoblasts seen in side view; *b*, a number of odontoblasts seen in end view, showing a terminal branch of a nerve fiber situated between the odontoblasts and the dentin (Huber).

drites ultimately form a loose plexus immediately under the layer of odontoblasts and, therefore, practically at the periphery of the pulp. Small branches pass from this plexus to terminate between the odontoblast cells, or pass through the layer of odontoblasts, but in no case have they been traced into the dentin. The sensitive dentin is, therefore, due to an indirect irritation of these nerve endings, conveyed to the latter through the medium of the

dentinal fibrils and the odontoblasts. The pulp is very sensitive to traumatic and chemical irritations, even when conveyed to it through the constituents of the dentin. It is especially sensitive to changes in temperature, heat or cold acting alike. It has no localized sensation of touch.

Our knowledge of the nerve supply of the peridental membrane is not extensive. Both medullated and non-medullated fibers are present, the latter being a part of the sympathetic nervous system, and accompany as well as innervate the small blood-vessels. The nerve fibers enter the peridental membrane in the same manner and from the same sources as the blood supply, which has already been described.

Attachment of Teeth.—In considering the attachment of teeth it must be remembered that teeth are not a part of the osseous system but are dermal appendages. The phylogenetic history of this subject in vertebrates is very interesting. The descriptive literature is extensive and many classifications of the different forms of attachment have been made. Tomes, in his "Dental Anatomy," classifies four forms of attachment: (1) by a fibrous membrane; (2) hinge-joint; (3) ankylosis; (4) insertion in a socket.

The attachment by *fibrous tissue* is manifest in the scaly teeth of sharks. Each cone-shaped tooth has a flattened dermal plate. Calcified connective tissue is built into this plate, which it unites more or less fibrously to the submucous matrix of the mouth. Such teeth are practically dermal scales and have no

direct attachment to the bony skeleton. The *hinge-joint* is merely a modification of the fibrous attachment, and is found in many fishes, reaching a high degree of development in the poison fangs of snakes. The hinge is composed of connective-tissue elements. In snakes the fang has a muscular attachment by which the reptile is able to erect the fang. By *ankylosis* is meant a direct calcified union with the bone of the jaw. Such teeth have no flattened base, but a calcified pulp which binds them firmly to the bony skeleton of the mouth. Ankylosis is confined to the teeth of certain fishes.

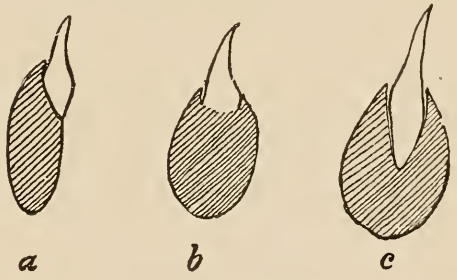


Fig. 122.—Diagram illustrating the development of a socket. *a*, Pleurodont dentition; *b*, acrodont dentition; *c*, thecodont dentition.

The development of a *socket* is associated with large teeth and a consequent strong attachment. The evolution of a socket is well represented phylogenetically in reptiles where Wiedersheim makes three classes: (1) *pleurodont dentition* (lacertilia), where "the teeth are situated upon a ledge on the inner side of the lower jaw, with which they become fused basally;" (2) *acrodont dentition* (chameleon,) where "they lie on the free upper border of the jaw;" (3) *thecodont dentition* (crocodiles), where "they are lodged in alveoli." In man all the teeth are imbedded in well-developed alveoli of the jaw-bones.

Here the function of the teeth is not only to seize and bite the food, but also to masticate it and test its quality. This change in function accounts for the heterodont dentition, which must have arisen by a modification of the simple homodont condition in which the teeth are all small, conical, and of the same size and shape. The primary arrangement of the teeth is such that those of one jaw do not usually correspond in position with those of the other, but rather with the interspaces between them. As a rule, the succession of teeth in man is nearly always reduced to two functional sets, the *deciduous*

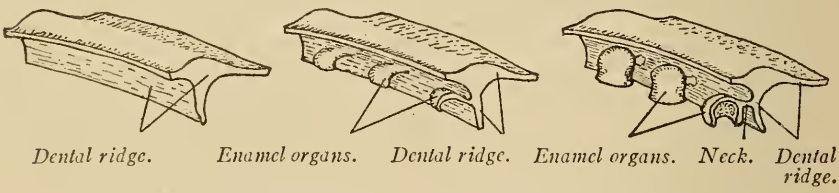


Fig. 123.—Diagram illustrating the development of the enamel organ of three teeth.

teeth and the *permanent* teeth. Traces of an earlier set have been found, which may be spoken of as a "predeciduous" dentition, and occasionally one or more teeth appear which replace corresponding permanent teeth, and thus indicate the possibility of an extra unrecorded set. An unlimited succession of teeth takes place in nearly all vertebrates, except with mammals.

Development of Teeth.—The enamel of the tooth develops from the epithelium of the oral cavity. In the seventh week of fetal life the mucous epithelium covering the gums invaginates to form a *dental groove*. The ridge or shelf thus invaginated is called

the *dental ridge*. Early in the third month this dental ridge produces lateral processes along its lingual side, one for each deciduous tooth. These epithelial processes or sacs are known as *enamel organs* and develop directly into the tooth enamel. A little later, during the third month, a second set of processes comes from the lingual side of the dental ridge and in like manner forms the *enamel organs* of the permanent set of teeth.

The origin of the *dentin* is closely associated with the *enamel organs* but comes from the connective tissue underlying these organs. This connective tissue forms *dental*

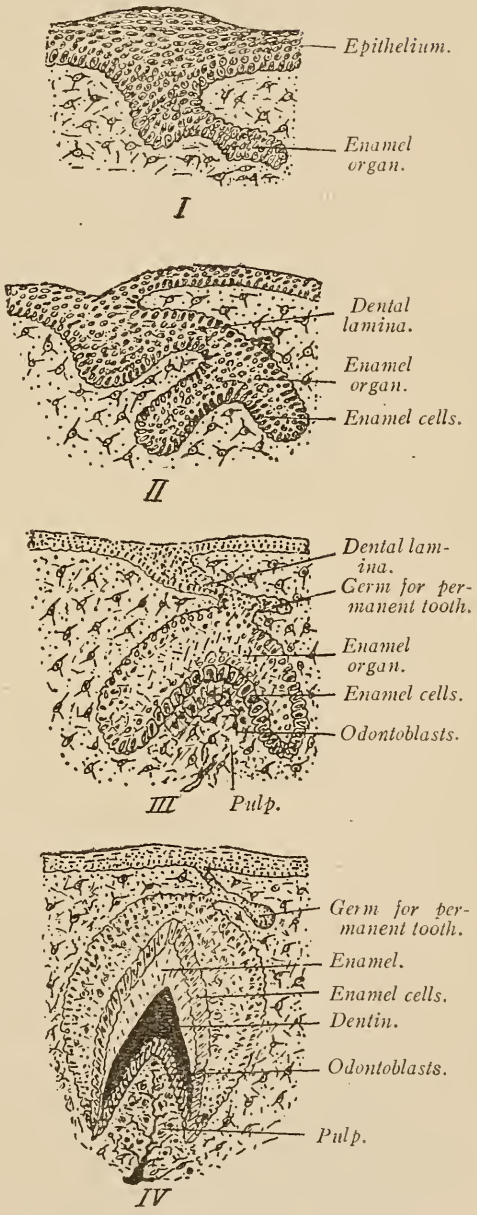


Fig. 124.—Diagram illustrating the development of a tooth.

papillæ, which later become differentiated into the *dentin* and *dental pulp*. The developing papillæ gradually become invested by the enamel organ and one by one erupt on the surface of the oral cavity either as deciduous or permanent teeth.

It will be observed that the enamel organs are sac-like structures consisting of an outer and inner layer of epithelial cells. The inner layer envelops the dental papillæ and is destined to form the enamel prisms. The outer layer becomes associated with an investing sheath of connective tissue, the *dental sac*, and serves as a temporary protection while the enamel is being formed. When the tooth erupts the outer lining of epithelial cells disappears.

The tooth papillæ are thus all preformed at the time of birth. They remain latent and develop regularly into the different teeth according to the table on page 144. A serious illness of a child just before their eruption may affect their healthy growth by interfering with proper nutrition, and imperfect and pitted teeth result, which often accounts for an early decay.

THE TONGUE.

The tongue is a voluntary muscular organ that occupies the floor of the mouth. In lower vertebrates the tongue is a prehensile organ. In many fishes it is covered with teeth, its function being to capture and hold prey. In frogs and toads it is covered with mucous and peculiarly modified to capture insects. In reptiles it is often bifurcated, very motile, and used to frighten an enemy. In

woodpeckers it is barbed and clearly a prehensile organ. In man, while the organ assists in taking

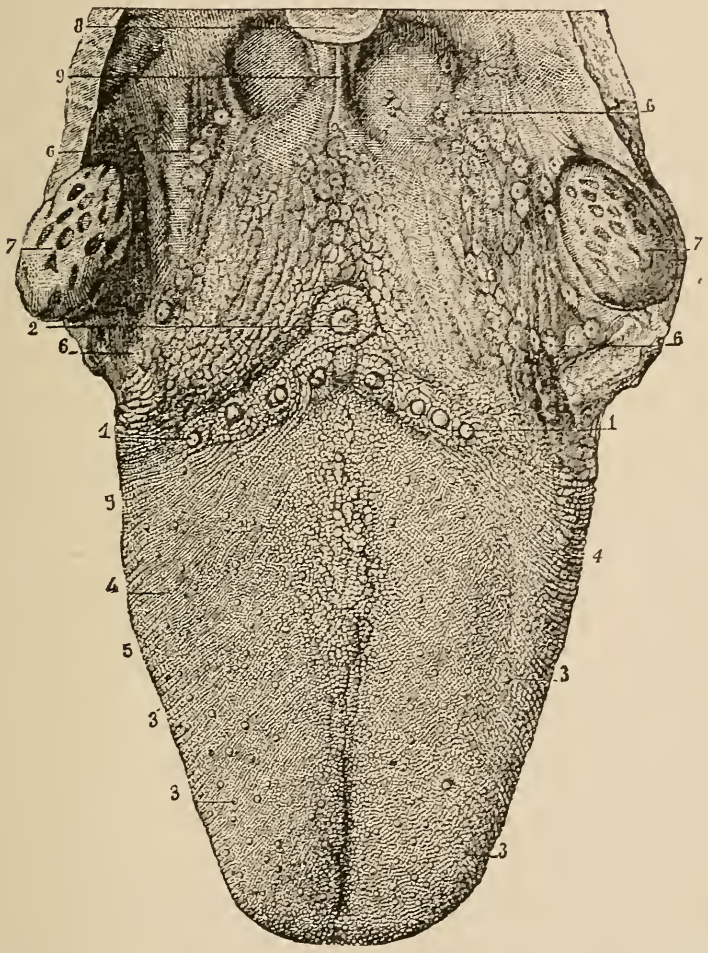


Fig. 125.—Papillar surfaces of the tongue, with the fauces and tonsils: 1, 1, circumvallate papillæ, in front of 2, the foramen cecum; 3, fungiform papillæ; 4, filiform and conical papillæ; 5, transverse and oblique rugæ; 6, mucous glands at the base of the tongue and in the fauces; 7, tonsils; 8, part of the epiglottis; 9, median glosso-epiglottidean fold (frænum epiglottidis) (from Sappey).

food, its more important function is gustatory, the taste organs being located upon its surface. For

description the tongue may be divided into *body*, *base*, *inferior surface*, and *dorsum*.

Body.—This is chiefly made up of striped muscle which may be divided into *intrinsic* and *extrinsic*. A median septum divides it into two symmetrical lateral halves. Connective-tissue elements, nerves, the body of glands, and blood-vessels interlace freely with the muscle. The musculature is best studied in a beef's tongue that has been boiled, and is a subject that belongs to gross anatomy. In any section of the tongue, muscle fibers will be seen both in cross section and in longitudinal section.

Base.—This is the posterior wide end of the tongue that is attached to the hyoid bone. It is covered with a smooth mucous membrane, beneath which is a rich supply of lymphoid tissue. The latter constitutes the lingual tonsil. Mucous glands are abundant.

Inferior Surface.—This is covered with smooth mucous membrane on which open many mucous and serous glands. The surface is divided into two halves by a fibrous septum which passes to the floor of the mouth and is known as the *lingual frenum*. When this is abnormally short the person is said to be tongue-tied, and speech is impaired.

The Dorsum.—This surface is convex both from before backward and from side to side. A median depression, or *sulcus*, divides it into lateral halves. The sulcus apex points backward to the *foramen cecum* just in front of the base. This *cecum* is a blind pocket that marks the origin of the middle portion of the thyroid gland, and is the remnant of

the obliterated thyroid duct. The dorsal surface is studded with three sets of papillæ, to be described in detail.

Papillæ.—1. *Filiform Papillæ.*—These are not only the smallest but by far the most numerous, and give the tongue a velvety appearance. They are arranged in divergent rows that extend outward and forward from the median sulcus. Each papilla is conical, points backward, and is covered by a thick

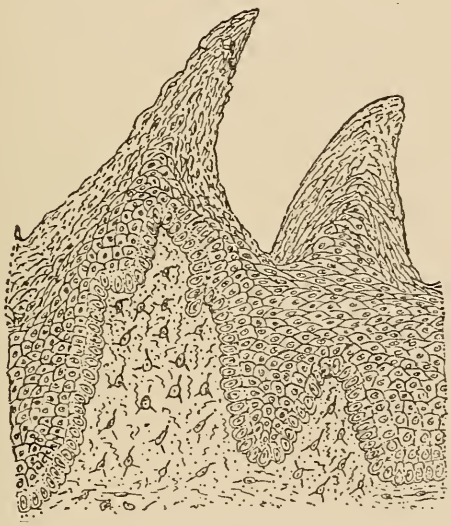


Fig. 126.—Section through two filiform papillæ of tongue.

layer of stratified, horny, squamous epithelium. The function of these papillæ is purely prehensile. In carnivorous animals they give the tongue a rasp-like structure that serves effectually in cleaning bones. It is said that a tiger, in this way, can draw blood from a living hand.

2. *Fungiform Papillæ.*—These are less numerous, larger, and supplied with blood, which gives them a

red color. They are most numerous at the tip and margins of the tongue. Each is like an inverted cone and has a covering of eight or ten layers of squamous epithelial cells. Many of these papillæ have taste buds in their lateral walls, analogous to those to be described in the third class of papillæ—the circumvallate. A connective-tissue papilla occupies the core of the fungiform. This core has a rich supply of blood-vessels which in fevers become congested with blood and give the dorsum a

Fig. 127.—Section of fungiform papilla of tongue.

speckled red color, spoken of as *strawberry tongue.* This is particularly the case in scarlet fever.

3. *Circumvallate Papillæ.*—These are by far the largest and are found just in front of the foramen cecum. They are about ten in number and are arranged in the form of a letter V, with the apex pointing backward. They resemble the fungiform papillæ, only they are much larger. Each papilla is surrounded by a deep, narrow, circular trench or

fossa, hence their name. The wall consists of stratified squamous epithelium and the core of connective tissue richly supplied with blood-vessels. From this core secondary connective-tissue papillæ indent the under surface of the stratified epithelial wall.

Taste Buds.—These are nests of epithelial cells that lie in the lateral walls of circumvallate and

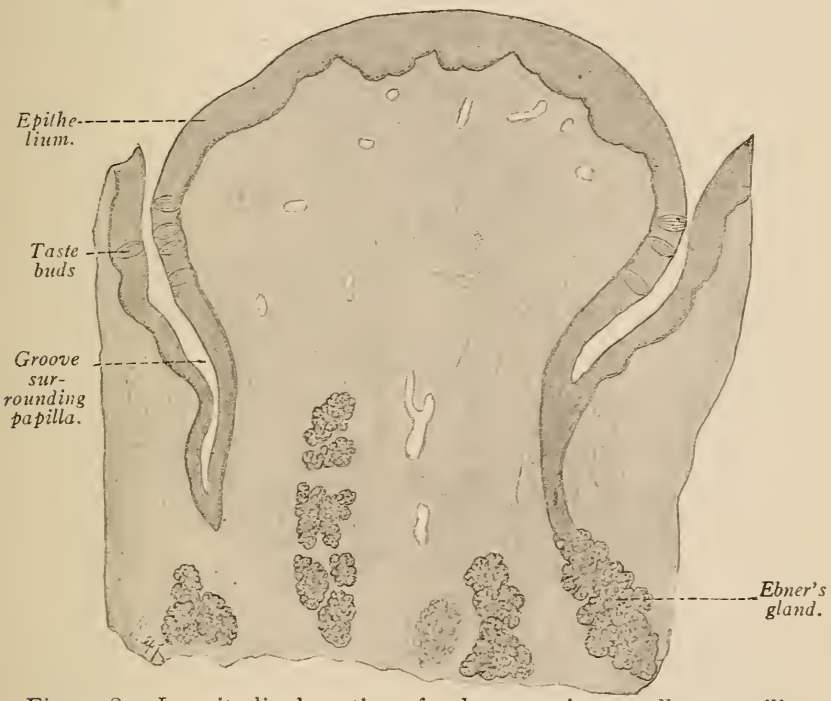


Fig. 128.—Longitudinal section of a human circumvallate papilla (Böhm and Davidoff).

many fungiform papillæ, and are closely associated with the sense of taste. They resemble small acorns, and are made up of columnar cells so arranged as to form a central *taste canal*, which in turn opens by a pore into the *circumvallate fossa*. Two kinds of slender epithelial cells are present, (1) *tegmental* or

cover cells, principally at the periphery of the bud, which support or ensheath (2) the *gustatory* or *taste cells*. The latter are smaller, more delicate and centrally placed, with the distal or free end bearing a small process that projects into the inner *taste pore*. The cells of the taste bud occupy the whole lateral wall; that is, the base of each cell rests upon the basement membrane next to the connective-tissue core and the distal end extends practically to the sulcus

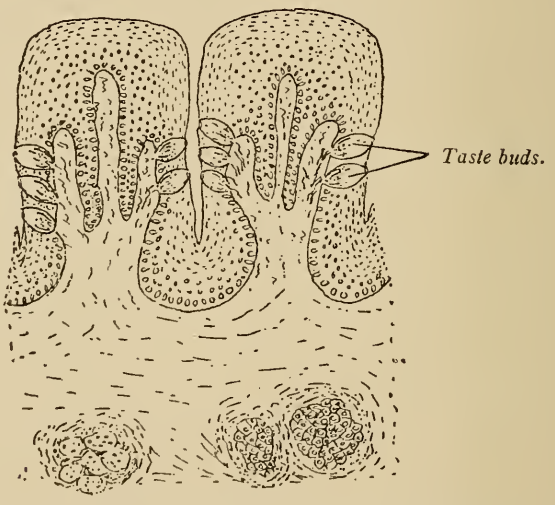


Fig. 129.—Two foliate papillæ from tongue of rabbit.

of the papilla. These taste buds, as a matter of protection, develop in the lateral wall rather than in the exposed dorsal surface of each papilla.

The nerve fibers of the gustatory nerve are not in protoplasmic continuity with the epithelial cells of the taste buds, as is the case with the sensory cells of the olfactory region. Nerve fibers enter the taste buds and terminate in varicosities that interlace and come in contact with the *gustatory* cells of each

taste bud. It is evident that a food to be tasted must first be put into solution to pass into the *sulcus* and stimulate the delicate processes of the gustatory cells of taste buds.

Foliate Papillæ.—On each side of the rabbit's tongue, some distance back, can be seen a small oval patch, with diagonal grooves and ridges, resembling the side of a three-cornered file. These patches are the *foliate papillæ*. In reality they are not papillæ but alternating grooves and ridges. In transverse section, the lateral walls of the ridges will be found beset with taste buds resembling in detail those

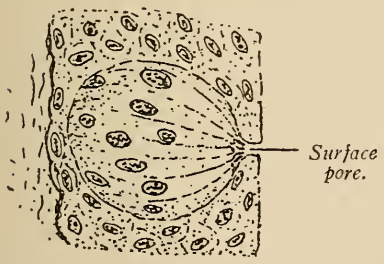


Fig. 130.—Section through taste bud.

Fig. 131.—Cells from a taste bud: *a*, taste cells; *b*, supporting cells.

described in the circumvallate papillæ. The rabbit, therefore, to relish his clover, should roll the leaves over these lateral patches.

Glands of the Tongue.—Small serous racemose glands are associated with the circumvallate papillæ into the *fossæ* of which their ducts open. Glands are otherwise absent over the dorsum of the tongue. Over the other parts of the tongue both serous and mucous glands are abundantly present. Many of these are mixed serous and mucous glands.

Blood Supply.—The arteries are the *lingual*, which branches to form (1) the *dorsal lingual artery* which anastomoses freely with the *tonsillar branch* of the facial, and (2) the *ranine artery* that passes along the under surface. The veins are the *ranine* and the *dorsalis linguæ* that drain into the internal jugular.

Nerves.—These are (1) the *hypoglossal*, the motor nerve; (2) the *lingual*, from the inferior maxillary of the *fifth*, which is accompanied by the *chorda tympani* of the *seventh*, or *facial;* (3) the *glosso-pharyngeal*, which supplies the taste buds; (4) the *internal laryngeal.* Many fibers of the sympathetic system mingle with these nerves.

PHARYNX.

The pharynx is the common passage for both food and air. It is an expanded portion of the digestive tube five inches in length and with seven openings: one, the fauces from the mouth; two posterior nares; two Eustachian tubes; one to the trachea, and the orifice of the esophagus.

The mucous membrane of the pharynx is lined with stratified squamous epithelium, except in the region of the posterior nares where the epithelium is ciliated. In the submucosa there is a generous supply of mucous and serous glands and lymphoid tissue. The latter is particularly abundant in the region of the posterior nares, forming in this location the *pharyngeal tonsils* or *adenoids.* In early youth the adenoids are prone to enlarge so as to obstruct normal breathing, a condition that justifies their removal. A rich supply of elastic longitudinal

connective-tissue fibers is also present in the submucosa. The submucosa is therefore capable of being greatly distended, as is the case in throat infections, such as diphtheria, where the congestion is so great as to interfere with respiration. The diphtheria germs and toxins are thus lifted up and walled off from the deeper structures and normal

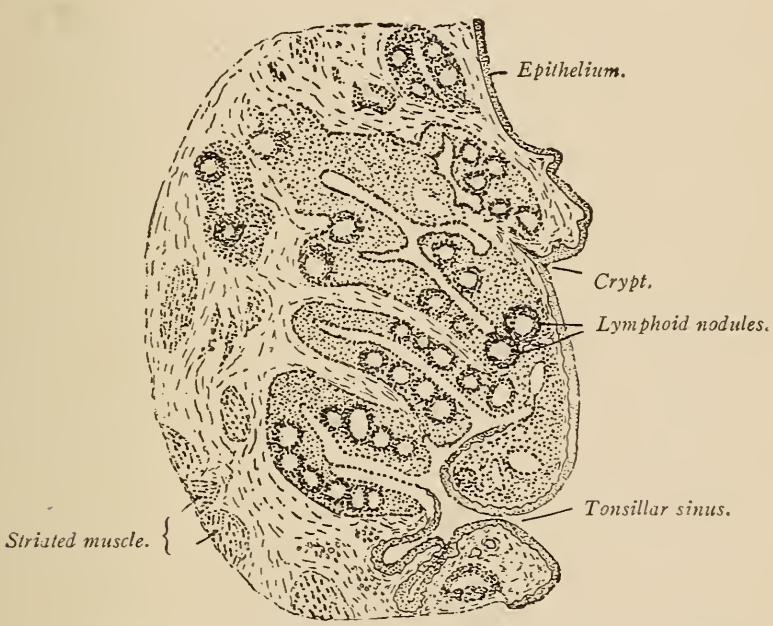


Fig. 132.—Section through the pharyngeal tonsil of man (Sobotta).

blood supply. This is nature's method of eliminating the disease, with the possible danger to the patient of suffocation.

External to the submucosa come several layers of striated muscle fibers forming the pharyngeal muscle, the description of which belongs to gross anatomy.

Tonsil.—The tonsils are two oval lymphoid masses imbedded in the lateral walls of the pharynx,

opposite the root of the tongue and between the anterior and posterior palatine arches. This lymphoid tissue is covered with the oral mucous membrane, beset with many depressions or pits known as *crypts*. It is along these crypts that bacteria may enter the tonsil, producing an inflammation of that organ known as *tonsillitis*.

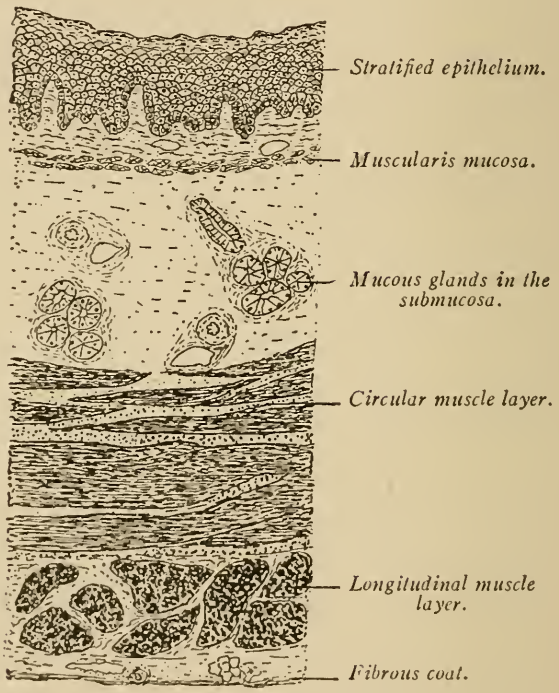


Fig. 133.—Cross section of the esophagus.

ESOPHAGUS.

The esophagus is the part of the alimentary canal that intervenes between the pharynx and the stomach, and is a very muscular tube about ten inches in length. Its upper end is opposite the lower border of the cricoid cartilage and the sixth cervical vertebra. The lower end or cardiac orifice is oppo-

site the eleventh dorsal vertebra. Two distinct constrictions are present, one at the beginning and one where it is crossed by the left bronchus. The normal distention at these points is about four-fifths inch.

The wall of the esophagus may be divided into four coats: *mucous*, *submucous*, *muscular*, and *fibrous*.

1. **Mucous Layer.**—This layer is thrown into many longitudinal folds and lined, as in the pharynx, with stratified epithelium. The tunica propria is well developed and may contain solitary lymph nodes. Tubular glands resembling those of the stomach are found in patches, particularly at the extremities of the esophagus. They are entirely confined to the mucosa and distinct from the mucous glands found in the submucosa. Their function is problematic. A *muscularis mucosa* is present in the esophagus just external to the tunica propria, consisting of longitudinally disposed smooth muscle cells. This layer becomes more prominent in the alimentary canal below the esophagus.

2. **Submucosa.**—This layer lies just external to the muscularis mucosa and consists of loose connective-tissue elements, blood and lymph vessels, nerves and the bodies of mucous glands. These glands are compound racemose and are particularly abundant in the lower part of the esophagus. The ducts pass through the muscular mucosa to open on the epithelial surface. They secrete mucus for the lubrication and protection of this surface. Not infrequently the morning vomit of mucus in chronic

gastritis comes from excessive secretion of these glands. The tissues of the submucosa are loosely held together, and sections, therefore, may tear along this layer.

3. **Muscular Coat.**—This consists of an inner circular and an outer longitudinal layer, although the fibers of each often interlace. The longitudinal layer is particularly strong, often thicker than the circular. In the upper half many striated fibers are present that are continuous with the pharyngeal voluntary muscle. The control of these fibers enables the dog to return food to the mouth that has passed into the upper part of the esophagus. In the lower half, only smooth muscle fibers are present. The longitudinal layer passes on as the longitudinal layer of the stomach and intestine, while the circular becomes the diagonal fibers of the stomach and does not pass to the intestine. Connective-tissue elements interlace and strengthen the whole musculature. Foods and liquids are carried along this tube by peristaltic contraction of its muscles, and in this way cattle and horses can take nourishment without lifting their heads.

4. **Fibrous Coat.**—This consists of loose connective-tissue elements, mostly white fibrous, binding the esophagus to adjacent structures. It is not well defined and often difficult to demonstrate as a distinct layer.

STOMACH.

The stomach varies greatly in form and position according to physiological conditions. For descriptive purposes it has two ends, *cardiac* and *py-*

loric; two surfaces, *dorsal* and *ventral;* two curvatures, *greater* and *lesser;* and two orifices, *esophageal* and *pyloric.* The most fixed point is the esophageal orifice, which is situated opposite the seventh left costal cartilage one inch from the sternal junction. The most movable portion is the pyloric end, which is situated one-half to one and one-half inches to the right of a median plane and a variable distance below the esophageal opening. The distance between

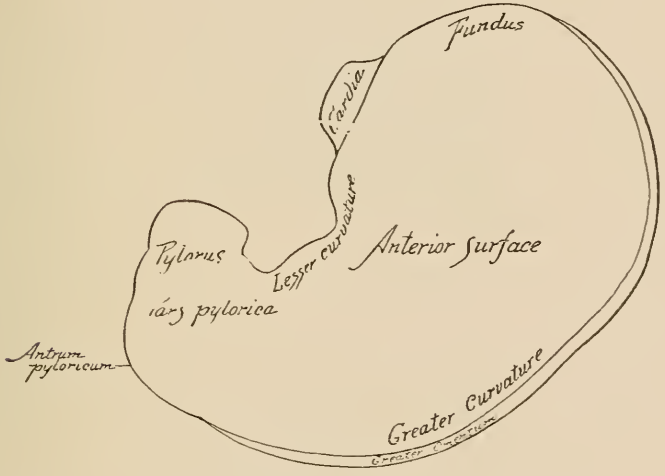


Fig. 134.—Anterior outlines of stomach. (His' model.)

the two orifices is about four inches. The full length of the stomach is about ten inches, and the greatest diameter four inches, with average capacity of one quart. These dimensions are subject to great variations.

The stomach wall, like that of other parts of the food canal, is made up of four layers: *mucosa, submucosa, muscularis,* and *serosa.*

1. **Mucosa.**—The mucous surface is uneven, due

to irregular folds. The surface is beset with minute pores or circular depressions, called *crypts*, into which the gastric glands open. As in other parts of the food canal this layer consists of *epithelium*, *membrana propria*, and *muscularis mucosa*. The *epithelium* is simple columnar with the nucleus near the bottom of the cell, leaving a clear proximal half

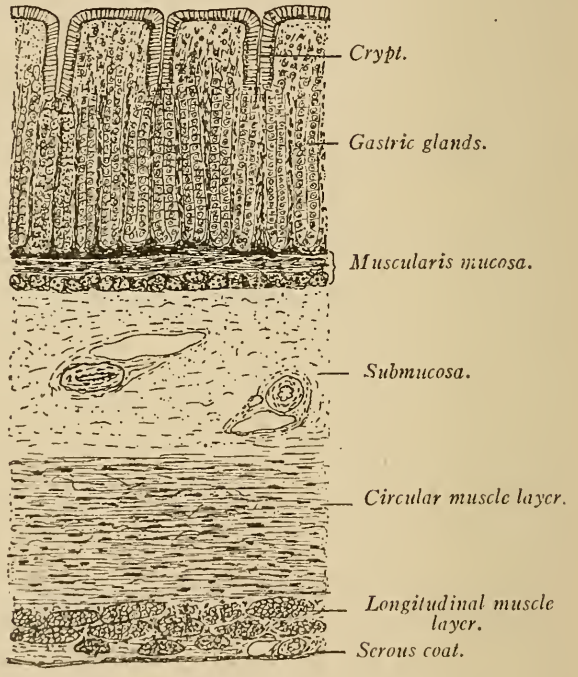


Fig. 135.—Cross section through the wall of a stomach.

to each cell that does not readily stain. The pits or crypts are lined by this same epithelium. The *membrana propria* has a rich supply of connective-tissue cells and extensive ramifications of blood and lymph capillaries. The *muscularis mucosa* is a thin muscle layer, external to the membrana propria, and consists of an inner layer of circular and an outer

layer of longitudinal smooth muscle fibers. A liberal supply of connective tissue is associated with this muscle. This layer, therefore, offers resistance to an invasion of bacteria, while the muscular contraction relieves pressure to the rich blood supply in the submucosa just external to it, and at the same time exerts pressure upon the gastric glands.

Gastric Glands.—These are widely distributed and perhaps the most important structures of the mucosa. They are simple tubular, except in the pyloric region, where many of them are branched. Usually several glands open into each crypt, the latter representing a circular pit-like evagination of the epithelial surface. The wall of each gland consists of simple epithelium and two kinds of cells are present: (1) *chief cells*, which are by far the most numerous; these are round or cuboid cells, with central nucleus that stains blue with hematoxylin; (2) *parietal cells*, which are less numerous, larger, and have a granular cytoplasm that takes the red eosin stain. They inter-

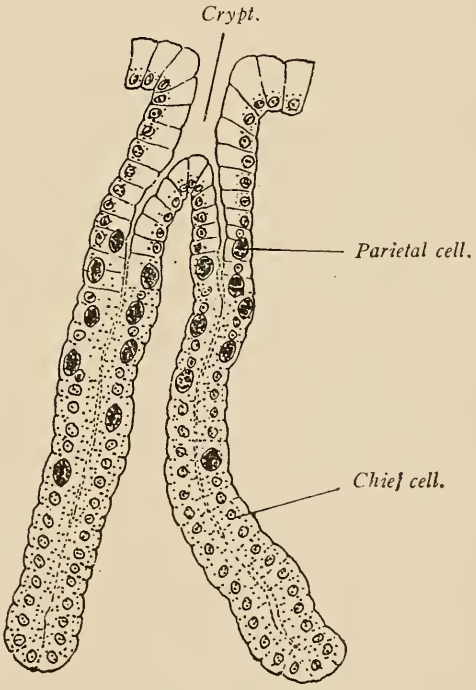


Fig. 136.—Simple tubular gland from stomach.

vene with the chief cells but are placed at the periphery of the glands, and communicate with the central lumen by means of a network of secreting ducts. They are most abundant in the cardiac end of the stomach and along the middle and inner third of each gland. These cells are supposed to have something to do with the secretion of hydrochloric acid. The cytoplasm of the chief cells contains granules of *pepsinogen*, which is converted into *pepsin* of the gastric juice. During fasting, these granules accumulate, and during, or after, active secretion they become smaller and tend to disappear.

Fig. 137.—A number of fundus glands from the fundus of the stomach of young dog, stained after the chrome-silver method, showing the system of fine canals surrounding the parietal cells and communicating with the lumen of the glands (Huber).

The mucosa secretes a varying amount of mucus for the protection of the delicate epithelial surface. In many forms of indigestion, and particularly in poison cases, the mucus secretion is very extensive and serves to keep the irritating stomach contents away from the epithelial lining. The excess of mucus can be removed by stomach lavage.

The chief difference between the pyloric and cardiac regions of the stomach is found in the mucosa. (1) The crypts in the cardiac end are shallow, while in the pyloric end the crypts frequently extend half way through the thickness of the mucosa. (2) The gastric glands

are longer than the crypts in the cardiac end; towards the pyloric end the glands become shorter, tortuous, and pressed closely against the muscularis mucosa. Many of the pyloric glands are branched. (3) The parietal cells are numerous in

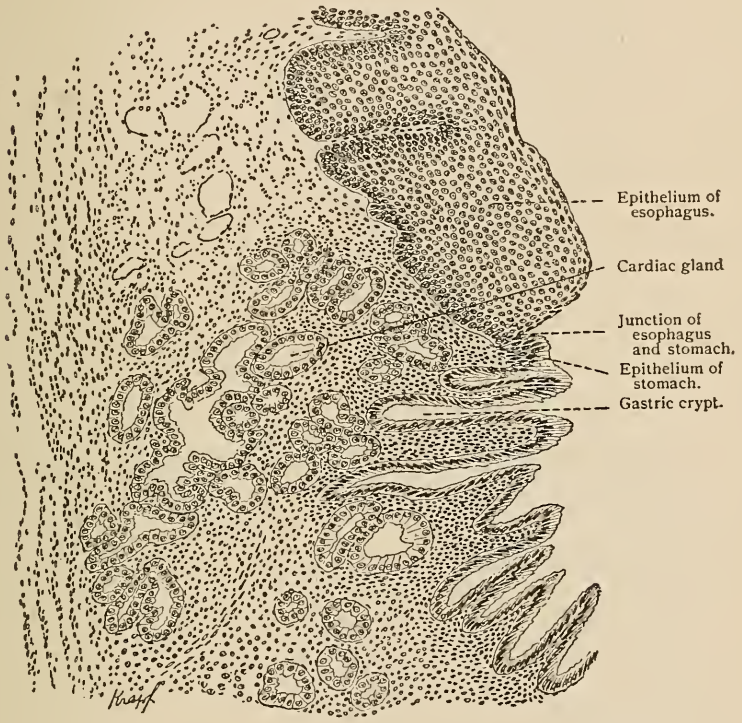


Fig. 138.—From a section through the junction of the human esophagus and cardia (Böhm and Davidoff).

the cardiac region and practically absent in the pyloric. The pyloric mucosa, in this way, comes to resemble that of the small intestine. In addition an occasional villus or Brunner's gland may be found in the pyloric end.

2. **Submucosa.**—The submucosa in all mucous membranes is highly vascular. Besides blood and lymph there is an abundant supply of connective-

tissue elements, largely elastic fibers, connective-tissue cells and fat cells. Nerve cells and nerve fibers, known as *Meisner's plexus*, are found here and in the submucosa throughout the alimentary canal.

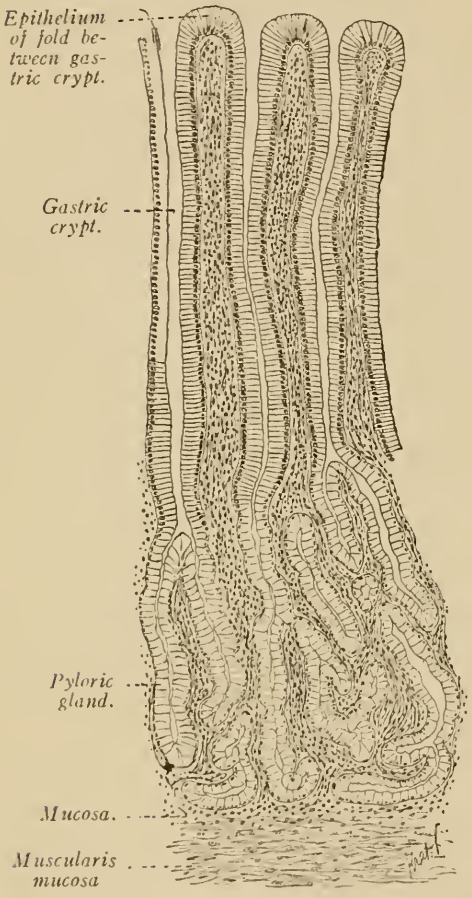


Fig. 139.—From vertical section through human pylorus (Böhm and Davidoff).

3. **Muscularis.**—This consists of smooth muscle and may be divided into three layers: (*a*) an inner sheath where the fibers run obliquely; this sheath is continuous with the circular layer of the esophagus; (*b*) a middle circular layer which is continued as the circular layer of the intestine; (*c*) an outer longitudinal layer continuous with the longitudinal layer of both esophagus and intestine; nerve cells and nerve fibers form a plexus between the longitudinal and circular muscle of the whole alimentary tract, which is known as the *plexus* of *Auerbach*.

4. **Serosa.**—This consists of a thin layer of fibrous tissue covered by simple pavement epithelial cells

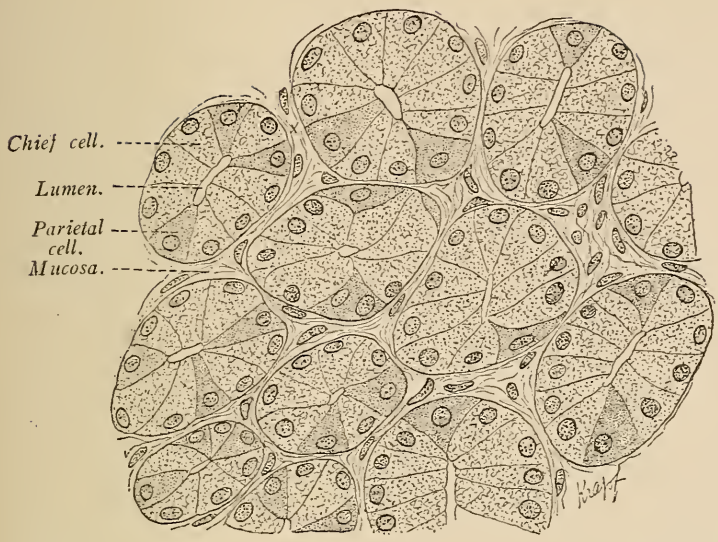


Fig. 140.—Section through fundus of human stomach in a condition of hunger (Böhm and Davidoff)

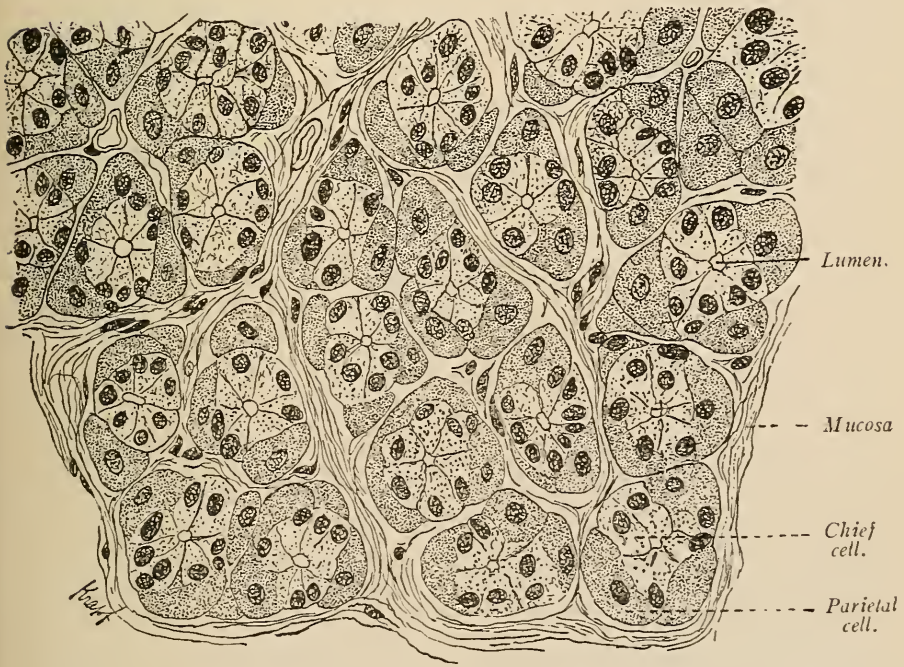


Fig. 141.—Section through fundus of human stomach during digestion (Böhm and Davidoff).

and bound down to the muscularis by delicate fibrous septa. It is really a part of the peritoneum.

The Stomach in Ruminants.—Ruminants (ox, sheep, goat, camel, llama) all have four compartments for the reception and maceration of food; *rumen*, *reticulum*, *omasum*, and *abomasum*. The first three are morphologically distensions and modifications of the lower end of the esophagus, while the abomasum alone corresponds to the stomach in other animals and needs, therefore, no further description here.

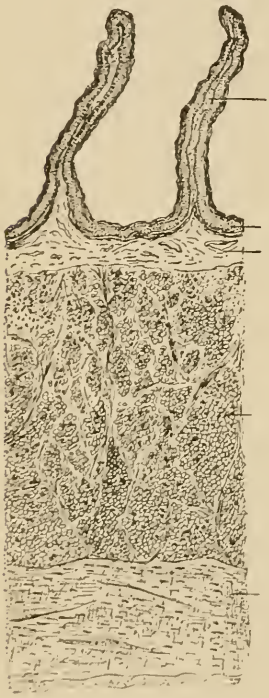


Fig. 141*a*.—Cross section through rumen of ox.

The Rumen is by far the largest compartment, reaching the enormous capacity of forty gallons in the ox. It is divided into four sac-like pouches by two muscular band-like girdles whose obvious function is to contract on the contents and render assistance in the mechanical process of returning food for further mastication. Its *mucous membrane* is covered with pointed papillæ 3 to 9 mm. in length, excepting where the muscular pillars are most prominent. Its epithelial lining is stratified, consisting of eight to twelve layers of cells, the

inner ones being very scaly and presenting a fibrous-like structure. The *submucosa* is vascular, with a scattering of small mucous glands, but these form no digestive secretion. Strands of smooth muscle fibers extend into the core of each papilla of the mucosa, also a net-work of blood and lymph vessels. There are two *smooth muscle* layers, an inner circular and an outer longitudinal, the inner layer being much the heavier. Like the esophagus, these layers show a fine cross-striation, and there is no doubt but that these layers assist in the mechanical process of returning the food to the mouth for a more thorough mastication. The *serosa* is unusually heavy and easily detected in microscopic sections.

The Reticulum is the second gastric reservoir and is the smallest compartment. Its *mucous* surface presents a honeycomb appearance when seen from the inside, hence its name. The *muscular tunic* is thin, otherwise the other layers are analogous to those found in the rumen.

The Omasum, or third compartment, is only a little larger than the reticulum. The *mucous membrane* is extensively folded to form large leaves extending the length of the organ. Between the large leaves are smaller leaves, and again a third and a fourth series, making altogether about 400 laminæ of variable sizes. These leaves bear horny papillæ, being large and pointed toward the reticulum end and small and warty toward the omasum end. These leaves are lined with eight to twelve layers of scaly, tesselated epithelial cells, forming a rough gritty surface. A liberal supply of smooth muscle is present in the center of each leaf, also a

network of blood- and lymph-vessels. The physiological action of this muscle causes adjacent leaves to rub against each other, producing a trituration of the retained food. The *muscular coat* is fasciculated and thin and composed of two layers that pass in different directions. The *serosa* presents nothing different from the general structure of the peritoneal lining.

SMALL INTESTINE.

The small intestine is about twenty-four feet long, and is divided into *duodenum*, ten inches: *jejunum* and

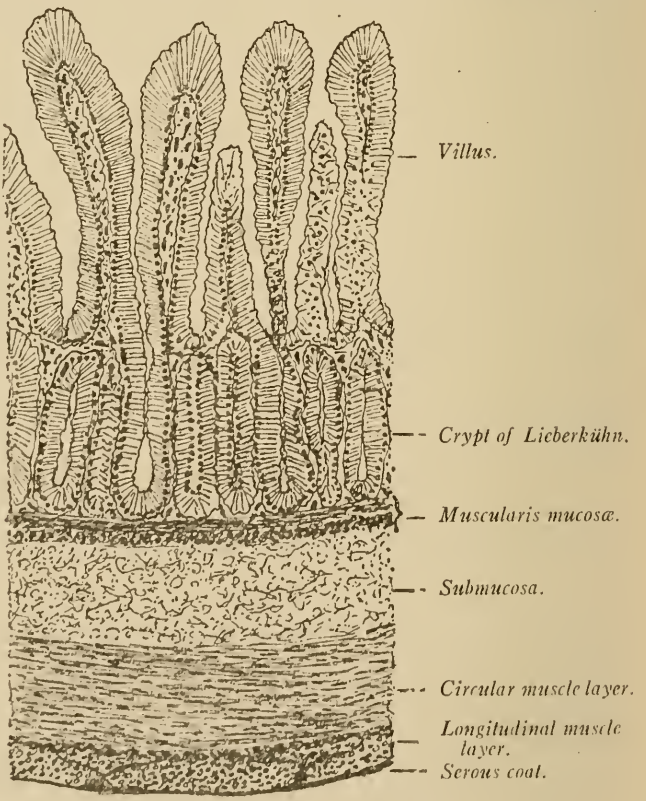


Fig. 142.—Cross-section of small intestine.

ileum, respectively, two-fifths and three-fifths of the remainder. About three feet from the lower end of

the ileum Meckel's diverticulum may be present, representing the last embryonic closure of the intestine. The intestine has the same number of layers as the stomach. The muscularis, however, consists of but two strata, an inner circular and an outer longitudinal.

1. **Mucosa.**—The mucosa is lined by simple columnar epithelium in which many goblet cells are present, particularly in the deeper folds. The membrana propria and muscularis mucosa are identical with those described in the stomach.

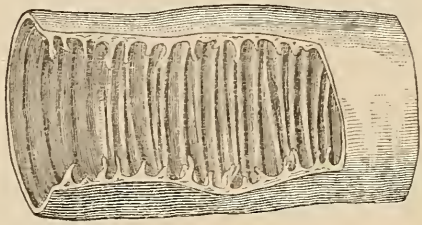


Fig. 143.—Portion of the wall of the small intestine, laid open to show the valvulæ conniventes (Brinton).

The mucous surface of the small intestine is much increased by means of folds, of which there are three mechanisms: *valvulæ conniventes*, *villi*, and *crypts of Lieberkühn*.

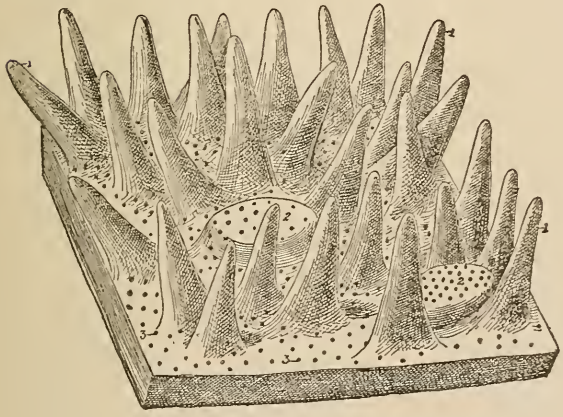


Fig. 144.—Mucous membrane of the jejunum, highly magnified (schematic): 1, 1, Intestinal villi; 2, 2, closed or solitary follicles; 3, 3, orifices of the follicles of Lieberkühn (Testut).

(*a*) *Valvulæ Conniventes.*—These are concentric, transverse, crescentic folds of the mucosa, that usually form two-thirds of a circle, although occasionally one forms an entire circle or even a spiral. These valves are two or three

inches long, about one-third inch broad and one-eighth inch thick. The inner surface of the small intestine is thus thrown up in a series of shelves. This mechanism has an analogue in the *typhlosole* of the earthworm and the *spiral valve* of some fishes.

(*b*) *Villi.*—These are tongue-like elevations of the mucosa one-thirtieth to one-fortieth inch in height, and barely visible to the naked eye. They are found on both sides of the valvulæ conniventes and on the general surface of the mucosa. Collectively they give the surface a velvety appearance. The villi are most numerous in the upper part of the intestine, where they number fifty to eighty to the square inch. They are longer but more slender and less numerous in the ileum, where they number forty to sixty to the square inch. Their total num-

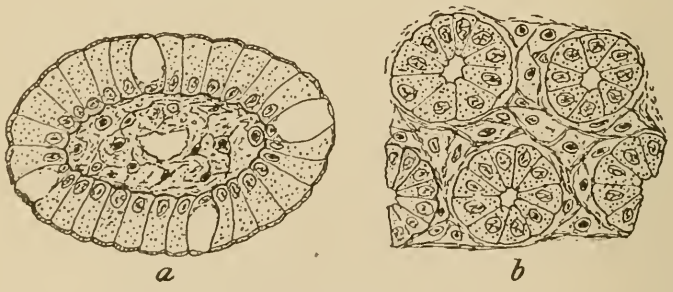


Fig. 145.—*a*, Cross section of a villus; *b*, cross section of crypt of Lieberkühn.

ber in the small intestine is estimated at 4,000,000. Each villus has a lining of simple columnar epithelium which covers a connective-tissue core. A few smooth muscle fibers enter this core from the muscularis mucosa. In addition there is a rich blood supply and a central lymphatic duct. The latter is a part of the lymphatic system of the intestine known as *lacteals* because of the milky

lymph they contain after each meal. The villi develop as invaginations of the mucosa and are exclusively confined to the small intestine.

(*c*) *Crypts of Lieberkühn.*—These are sometimes spoken of as intestinal glands. They consist of pits or *evaginated diverticulæ* of the mucous epithelium that open as pores between the bases of the villi. The bottom of these crypts rests against the muscularis mucosa. Goblet cells are particularly numerous in the epithelial lining of their walls. Crypts

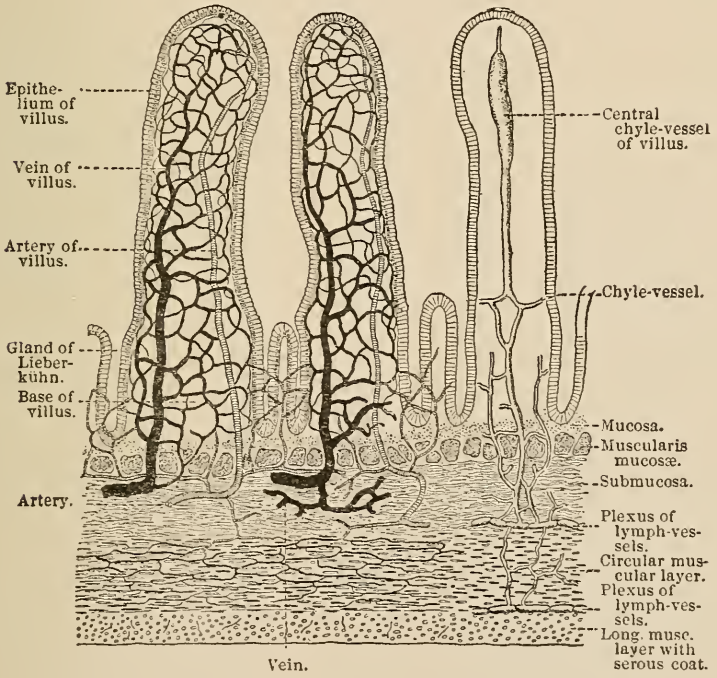


Fig. 146.—Schematic transverse section of the human small intestine (after F. P. Mall).

are also present in the large intestine and are analogous to the shorter crypts of the stomach into which the gastric glands open.

Solitary Lymph Nodules.—These are simple nodes

of lymph tissue situated just beneath the mucous epithelium. They are found along the whole alimentary tract and in all mucous membranes.

Peyer's Patches, or *Agminated Lymph Nodules.*—These appear as oval elevations on the mucous surface and are collections of lymph nodules. They may be three inches long or less, and one-third to one-half inch broad. They number from thirty to forty, and are found in the ileum and always in the mucous surface opposite the mesenteric attachment, the long axis being parallel with that of the intestine. Their bodies usually extend to the circular muscle layer and they therefore invade the submucosa. Villi are either stunted or altogether absent over these patches. In early youth they are very prominent, while in middle life they begin to atrophy, and in old age they may entirely disappear.

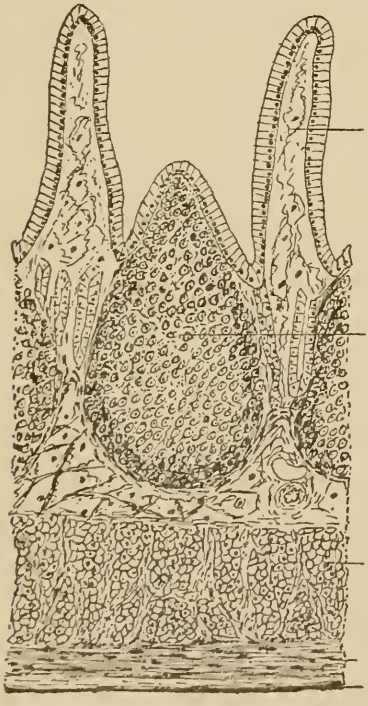


Fig. 147.—Longitudinal section of ileum showing part of a Peyer's patch.

The patches are the seat of ulcerations, particularly in typhoid fever and tuberculosis. The latter form transverse ulcers as the bacteria of tuberculosis

spread along the lymphatics which are here transverse to the intestine. The typhoid germ produces an ulcer whose long axis is parallel to that of the intestine.

Brunner's Glands.—These are branched tubular glands whose bodies are situated in the submucosa and whose ducts pass through the muscularis mucosa to open between or into the crypts of Lieberkühn. They are confined to the duodenum, particularly the upper part. Occasionally they may be found in the pyloric end of the stomach. The cells resemble those of the pyloric glands, being cylindrical and finely granular. Brunner's glands are easily recognized, as they are the only glands that lie in the submucosa.

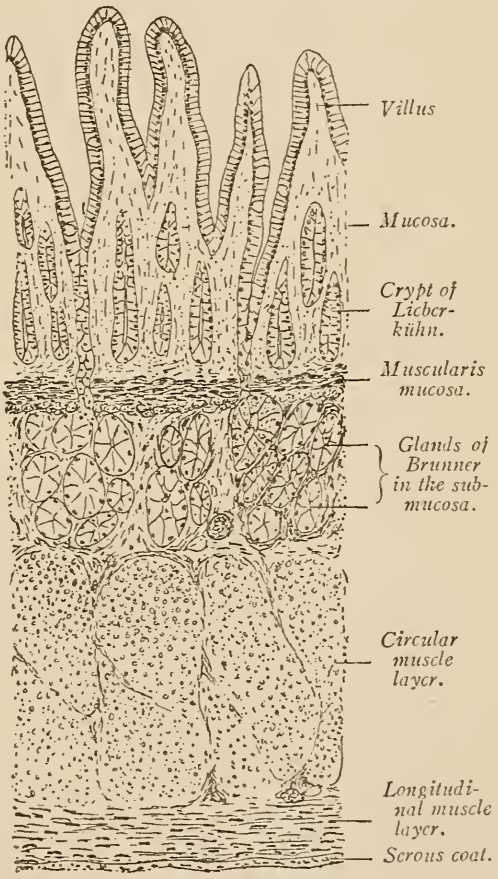


Fig. 148.—Longitudinal section of duodenum near pyloric end, showing glands of Brunner.

2. **Submucosa.**—The submucosa does not differ from the same layer already described in the wall of the stomach.

3. **Muscularis.**—The muscularis consists of an inner circular and an outer longitudinal layer of smooth muscle. The inner circular is the heavier of the two and by its contraction produces many longitudinal folds in the mucosa. Smooth muscle, wherever found, is associated with connective-tissue elements, but the smooth muscle of the intestine has a less supply of this than the smooth muscle any other place in the body.

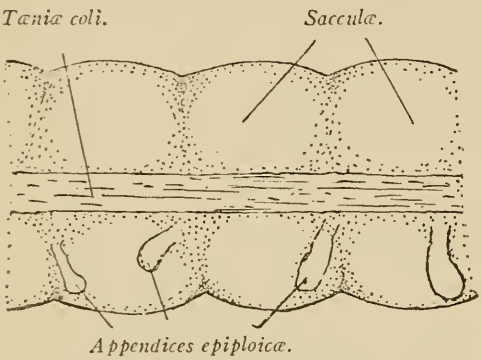


Fig. 149.—Portion of large intestine.

4. **Serosa.**—This layer is identical with the serosa described in the wall of the stomach.

LARGE INTESTINE.

The average length of the large intestine is five feet. Its divisions are given on page 128. It is distinguished from the small intestine by the following external features: *tæniæ coli*, *sacculæ*, and *appendices epiploicæ*.

Tæniæ Coli.—In the large intestine the longitudinal muscle is gathered into three bands or strips known as tæniæ coli. Each band is about one-quarter inch wide and one foot shorter than the intestine to which it belongs. The large intestine, therefore, becomes *sacculated*—that is, it is divided by the three longitudinal muscle bands into three rows of sacculæ. If the bands be dissected away the saccules

disappear and the intestine becomes about one foot longer.

Appendices epiploicæ are small pedunculate processes that project from the serous coat of the large intestine. The pouches are covered by the peritoneum and are usually distended with fat. These external features are the surgeon's guide in recognizing the large intestine. Size is a less reliable factor.

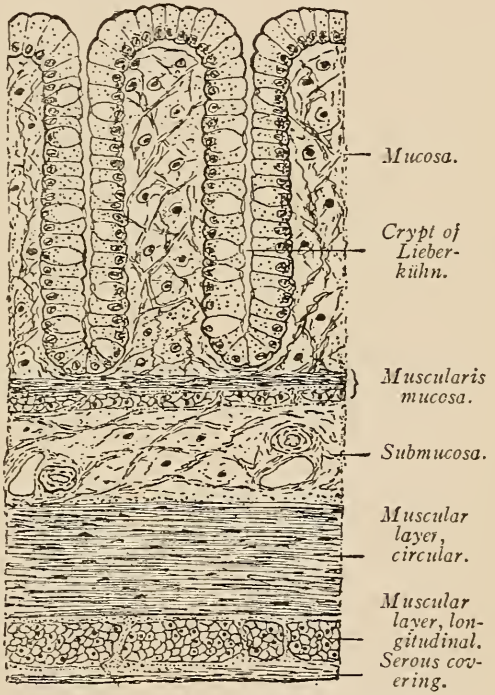


Fig. 150.—Cross section of large intestine, showing many goblet cells in epithelium.

Structurally the large intestine has the same four layers as the small intestine. The three outer layers are identical. The mucosa presents a smooth surface with numerous minute circular pits, the crypts of Lieberkühn. As villi are absent the mucosa resembles that of the stomach rather than that of the small intestine. The crypts of the stomach are shallow, while those of the intestine are deep and extend to the muscularis mucosa. Each crypt is lined by simple columnar epithelium. Goblet cells are very numerous in this epithelium.

Vermiform Appendix.—The appendix, although very small, belongs to the large intestine. It is a worm-like tube about three inches long and one-quarter inch thick, although the length varies greatly. It is a blind tube that evaginates from

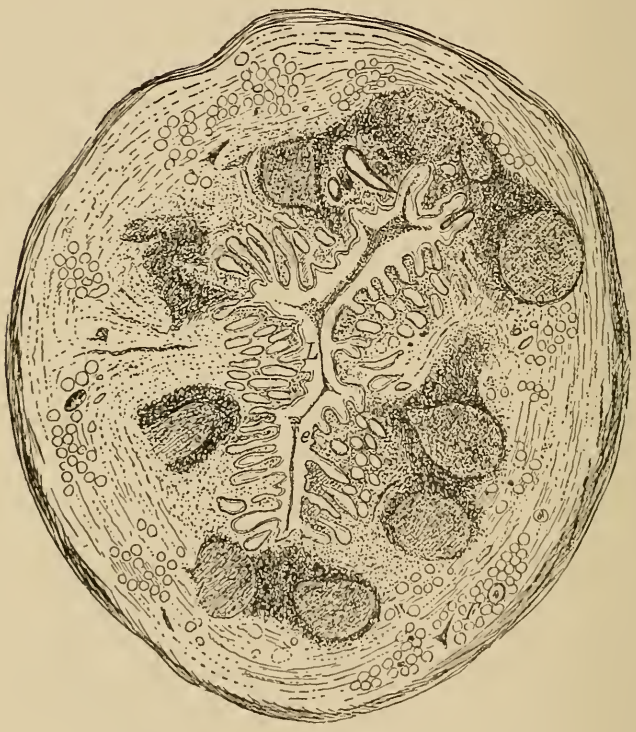


Fig. 151. — Transverse section of human vermiform appendix. Observe the numerous lymph nodules. The clear spaces in the submucosa are adipose tissue (Sobotta).

the lower end of the cecum. Lymph nodes are particularly abundant in the mucosa of the appendix.

The following taken from Cunningham's "Anatomy" will be of interest to the student: "A vermiform process is found only in man, the higher apes,

and the wombat, although in certain rodents a somewhat similar arrangement exists. In carnivorous animals the cecum is very slightly developed; in herbivorous animals (with a simple stomach) it is, as a rule, extremely large. It has been suggested that the vermiform process in man is the degenerated remains of the herbivorous cecum, which has been replaced by the carnivorous. Another and perhaps more probable view regards the appendix as a lymphoid organ, having the same functions as Peyer's patches and, like these, undergoing degeneration after middle life" (Berry).

In the different parts of the alimentary canal the mucosa shows a marked variation, as represented in the following table:

Esophagus.	*Stomach.*	*Small Intestine.*	*Large Intestine.*
Stratified epithelium.	Simple epithelium.	Simple epithelium.	Simple epithelium.
Mucous glands.	Gastric glands.	Brunner's glands.	Crypts.
Crypts absent.	Crypts shallow.	Crypts of Lieberkühn.	Crypts.
Villi absent.	Villi absent.	Villi present.	Villi absent.
Valvulæ absent.	Valvulæ absent.	Valvulæ conniventes present.	Valvulæ absent.

Blood Supply of Stomach and Intestines.—The arteries of the stomach are all derived from the celiac axis, a branch of the aorta. The intestines are supplied by blood from the superior and inferior mesenteric arteries, branches of the aorta. The arteries enter along the line of the mesenteric attachment and there form branches that pass transversely around the intestine to ultimately penetrate the longitudinal muscle layer. Between the two muscular coats branches are given off to supply the

muscles themselves. The arteries then penetrate to the submucosa where an extensive blood plexus is formed. From this plexus branches pass through the muscularis mucosa and enter the mucosa. Here

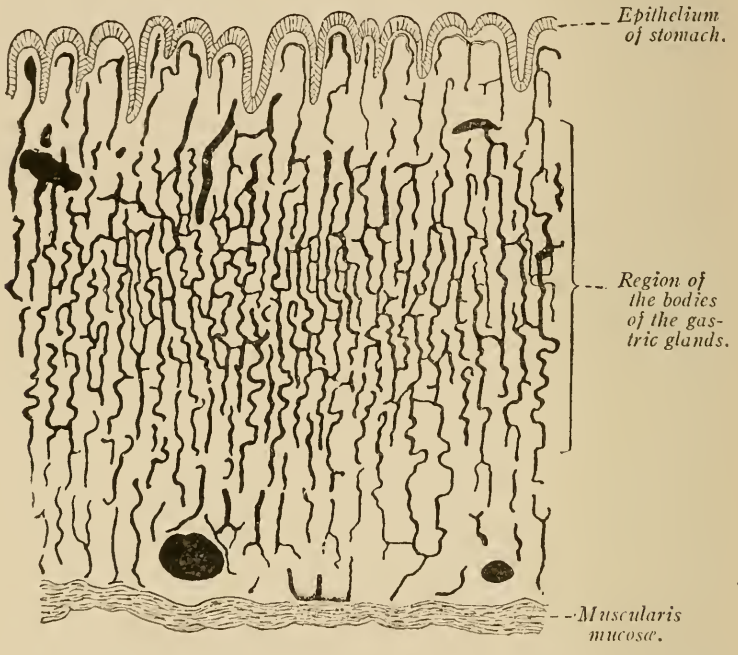


Fig. 152.—Section through fundus of cat's stomach. The blood-vessels are injected (Böhm and Davidoff).

they branch into a fine capillary network which in the small intestine penetrates to the core of the villi. Other branches from this plexus supply the inner portion of the circular muscle layer.

The veins lie side by side with the arteries. Often two veins accompany one artery. The blood drains into the superior and inferior mesenteric veins; the inferior joins the splenic, and the latter unites with

the superior to form the portal vein. This blood thus ultimately passes through the liver.

Lymphatics of the Alimentary Canal.—The lymphatics begin in the mucosa just beneath the epithelium. In the small intestine they begin with the central lymph vessel of a villus. These vessels form a network in the deeper portion of the mucosa and then pass through the muscularis mucosa to form

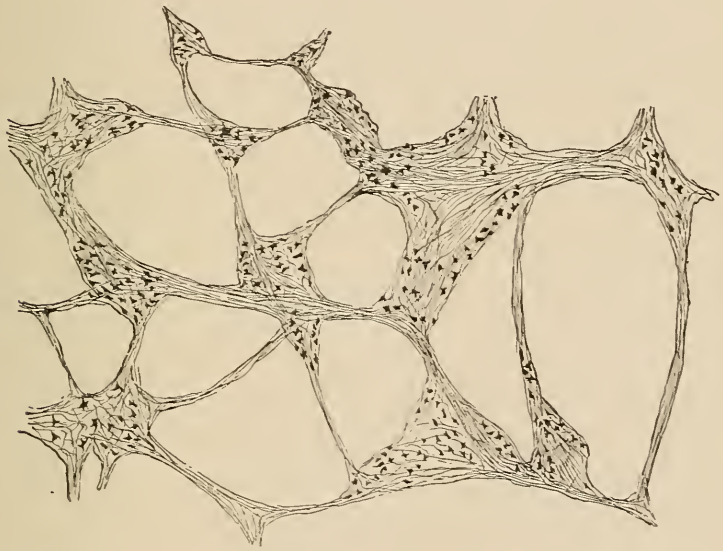


Fig. 153.—A portion of the plexus of Auerbach from stomach of cat, stained with methylene-blue (*intra vitam*), as seen under low magnification (Huber).

an extensive loose plexus in the submucosa. Coarser lymphatic vessels lead from this plexus through the muscularis, where branches are received from a lymphatic plexus located between the two muscle coats.

The solitary lymph nodes of the mucosa contain no lymphatics, but are encircled at their periphery

by an extensive lymphatic network. The same is true of the lymph nodules in Peyer's patches.

Nerve Supply of the Alimentary Canal.—The chief nerve supply of the alimentary tract consists of sympathetic neurons whose nerve cells form the centers of two plexuses, (1) that of Auerbach, situated between the two layers of the muscle coat, and (2) that of Meissner in the submucosa. The latter contains fewer ganglia and finer fibers. The numerous small sympathetic ganglia of each plexus are united by small bundles of non-medullated nerve fibers in which a few medullated nerve fibers are present. From these plexuses the nerve innervation extends to the glands and epithelial cells of the mucosa, and to the muscularis to end in small varicosities about the smooth muscle cells.

While the nerve innervation is not under will control it is capable of being stimulated by cerebrospinal nerves. Medullated nerve fibers from this system have been traced to terminal end baskets surrounding cell bodies of many of the sympathetic neurons of these plexuses.

CHAPTER V.

DIGESTIVE GLANDS.

SALIVARY GLANDS.

1. **Parotid Gland (serous gland).**—This is a compound tubular gland, the largest of the salivary glands, situated in the parotid recess at the side of the head below and in front of the ear. It is a triangular mass that varies in weight from one-half ounce to one ounce or more. Its three surfaces are designated as *superficial*, *anterior* and *posterior*. The gland is divided into lobes and lobules and interlaced with connective-tissue elements from the parotid fascia that invests it.

The *parotid*, or *Stenson's duct*, measures from one and one-half to two and one-half inches in length and one-eighth inch in diameter. It runs forward across the masseter muscle, passes around the anterior border of this muscle, pierces the buccinator, then forward a short distance to open on the inner surface of the cheek opposite the crown of the second upper molar. This duct is subject to injury in facial wounds or operations.

The gland is an epithelial organ and consists of the *excretory duct*, *interlobular*, *intralobular*, and *intercalated ducts*, and the *distal convoluted tubules* or *alveoli*. The excretory duct (Stenson's) is lined by stratified epithelium near its end where it opens on

the mucous surface of the cheek. The rest of the duct is lined by two layers of cubical epithelium, which is invested by a firm fibrous coat or tunica propria. The *interlobular ducts* lie between the

Fig. 154.—Section through salivary gland of rabbit, with injected blood-vessels (Böhm and Davidoff).

lobules and have much the same histology as the excretory duct, excepting the finer branches where the epithelium becomes simple cubical. The *intralobular ducts* are found inside the lobules and have a simple layer of tall cylindrical cells whose cytoplasm

shows a distinct longitudinal striation. The *intercalated pieces*, on the other hand, are clothed by a single layer of flat, slender, often spindle-shaped cells. The epithelial lining of the acini consists of typical serous-gland cells. This is a single layer of irregular columnar or cubical cells with nuclei situated near their basal portion. When at rest the cytoplasm is filled with zymogen granules which are used up and largely disappear during the process of secretion. Mumps is a specific disease of this gland, more technically known as *parotitis*.

2. **Sublingual Gland (mucous gland).**—This is really a collection of compound tubulo-alveolar glands. It is an elongated flattened mass one and one-half to one and three-quarter inches in length, situated in the floor of the mouth, one on each side of the median plane, and limited laterally by the ramus of the mandible. Its excretory ducts, from ten to twenty in number, open separately on the summit of papillæ visible to the naked eye, which are situated just laterally to the base of the frenum of the tongue.

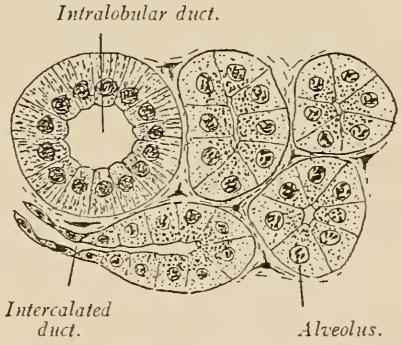


Fig. 155.—From the parotid gland of man.

The duct system of the gland is similar to that of the parotid, with the exception of the intercalated piece, which is absent. The alveoli are less tubular than those of the parotid and are lined by simple

columnar epithelium with the nuclei situated at the base of the cells near the basement membrane. These are the *chief cells* of the alveoli and they secrete mucus, which is first stored up in the cytoplasm in coarse granules known as *mucigen*. A second form of cells, less numerous, is found singly or in groups in the periphery of the alveoli and in close apposition to the basement membrane. On account of their shape and position they are called *parietal cells*, *crescents of Gianuzzi*, or *demilunes of Heidenhain*. They are finely granular, stain red with eosin, and are looked upon by some as secreting a serous fluid. There are three theories as to their use: (1) They may be considered as worn-out chief cells that have been crowded to the basement membrane after too active a secretion. (2) They may be considered as latent undeveloped cells ready to take the place of mucous cells that get lost in the process of active secretion. (3) They may be considered as normal active cells contributing constantly to the salivary secretion in a way that is at present unknown.

Fig. 156.—Model of a small portion of a sublingual gland of man. The demilunes of Heidenhain are more deeply shaded (Maziarski, "Anatomische Hefte," 1901).

3. **Submaxillary Gland (mixed gland).**—In man this gland is composed of tubules having a serous secretion and similar to those of the parotid gland, and tubules with alveolar enlargements like the sublingual gland that secrete mucus. Its histology, therefore, would be a repetition of what has already been described in the parotid and sublingual glands.

The submaxillary gland is next in size to the parotid, which it resembles in color and lobulation. It

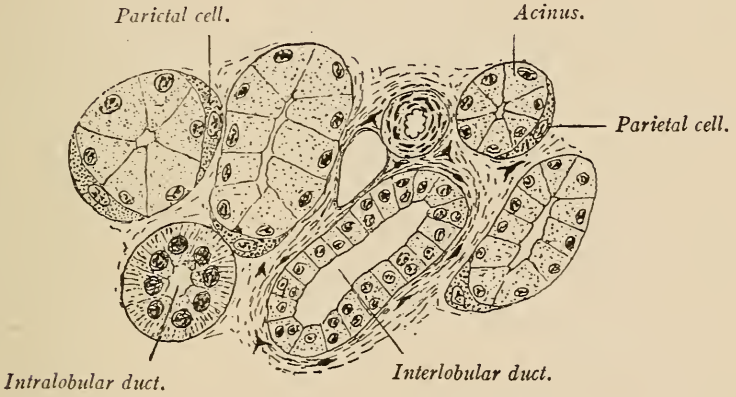


Fig. 157.—Section from the human submaxillary gland

is placed against the inner surface of the angle of the lower jaw in close proximity to the parotid gland. It has a complete firm capsule derived from the cervical fascia. Connective-tissue elements from the capsule ramify between the lobes and lobules of the gland.

The *submaxillary*, or *Wharton's duct*, is about two inches long, passes forward beneath the mylohyoid muscle, then along the inner side of the sublingual gland to open on the summit of a small papilla situ-

ated in the floor of the mouth at the side of the frenum of the tongue in close proximity to its fellow of the other side. The submaxillary gland of the rabbit is a serous gland; that of the dog and cat is mucous.

Fig. 158. — A number of alveoli from the submaxillary gland of dog, stained in chrome-silver, showing some of the fine intercellular tubules (Huber).

The **accessory salivary glands** are numerous small glands of the mouth known according to their location as *labial*, *palatine*, and *lingual*. They are mostly glands with mucous secretions. Branched tubular glands with serous secretion occur in the tongue, their ducts opening into the depressions of the circumvallate papillæ.

PANCREAS.

The *pancreas* is a lobulated compound racemose gland analogous in its structure to the salivary glands. It is situated transversely across the posterior wall of the abdomen, so deep in the body and so closely associated with other organs that but little is known of its diseases. Its length varies from six to eight inches, its breadth one and one-half inches and thickness from one-half to one inch. The right extremity, or *head*, rests in the concavity of

the duodenum and the other end touches the spleen. It lies behind the peritoneum and, unlike the salivary glands, it is not enclosed in a fibrous capsule, and is therefore looser and softer in its texture.

The pancreas develops as two evaginations of the alimentary canal and embryologically, therefore,

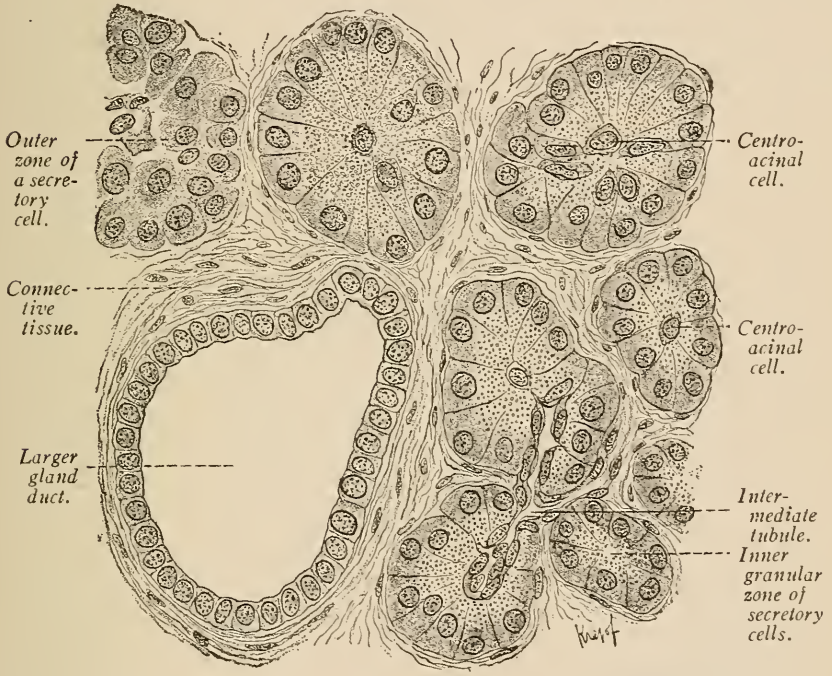


Fig. 159.—From section through human pancreas (sublimate) (Böhm and Davidoff).

has two ducts. One of these, the *pancreatic duct*, or *duct of Wirsung*, opens jointly with the bile duct on the summit of an elevated papilla, situated at the inner side of the descending portion of the duodenum. This duct extends the length of the pancreas and receives in its course the short ducts from the various lobes composing the gland.

The second duct, or *duct of Santorini*, loses its connection with the alimentary canal and comes to open into the duct of Wirsung. It is a very short tube, inferior in position and secondary in importance.

Histologically, the ducts are lined by a mucous membrane of simple columnar epithelial cells that are morphologically continuous and analogous with the epithelial cells of the intestine. This mucous

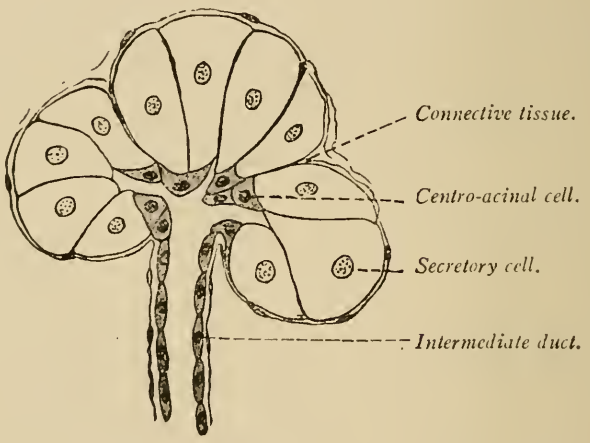


Fig. 160. — Scheme showing relation of three adjoining alveoli to excretory duct, illustrating origin of centro-acinal cells (Böhm and Davidoff).

membrane is ensheathed by a coat of connective-tissue elements, fibers and cells, all of which are associated with more or less fat.

The *acini* resemble in form and size those of the salivary glands. The parietal cells are absent. The *chief* cells are columnar, the nucleus near the base of the cell, and the cytoplasm loaded with zymogen granules. During physiological activity these granules are greatly reduced. In addition, *centro-acinal*

cells are present. These are smaller and flatter than the chief cells and occupy a central position of many acini. They represent an invagination of the neck of the acinus and are best understood by referring to Fig. 160.

Areas of Langerhans.—These are oval cell masses that measure 0.2 to 0.3 mm. They are found in the lobules of the pancreas, always associated with the connective tissue but having no connection with the

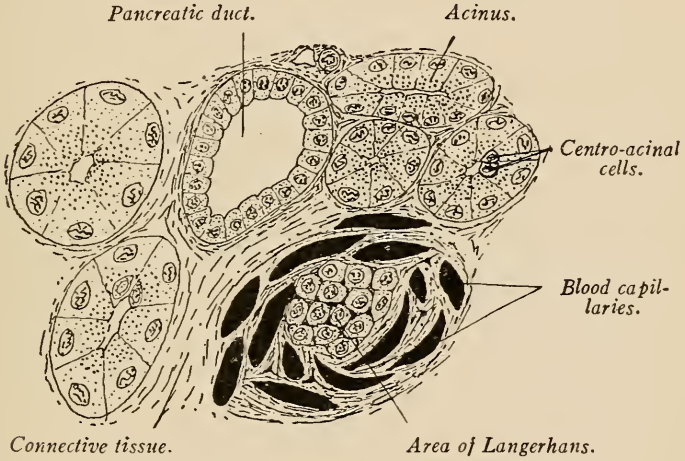


Fig. 161.—Section from an injected pancreas of the dog.

pancreatic tubules. The areas are surrounded by a rich supply of coarse capillary blood-vessels. The individual cells are epithelioid, smaller than those of the acini, and finely granular. In many respects they resemble the liver cells. It is believed that the secretions from these cells is absorbed by the blood and modifies the distribution and elimination of sugar. The areas thus have a compensatory relation to the liver and may do in part the work of that organ. A marked disturbance in these areas has

been observed in diabetes, but whether a cause or consequence is not known.

LIVER.

The *liver* is a large compound tubular gland whose terminal ducts anastomose. In this respect it differs from any other gland in the body. It develops as a ventral evagination of the intestinal wall and in close proximity to the origin of the pancreas, so that in the adult the ducts of these two organs have a

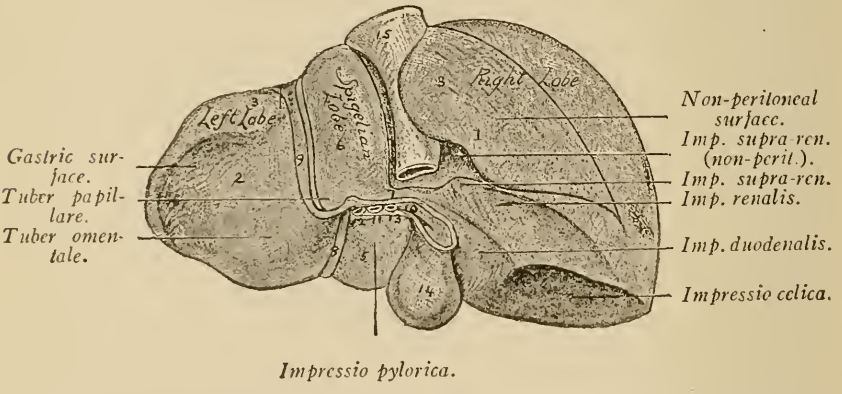


Fig. 162.—Posterior and inferior surfaces of the liver (Nancrede).

common opening at the apex of a papilla, as already mentioned in the description of the pancreas. If an obstruction occurs at this opening, it is possible for the pent-up bile to invade the pancreas. The ventral liver diverticulum quickly bifurcates to form respectively the right and left lobes of the liver. By repeated divisions the bile system of the organ is built up, forming an elaborate anastomosis of the finer bile capillaries. It follows, therefore, that the liver cells are genetically related to the pancreatic

cells and sister cells of the columnar epithelium of the alimentary tract.

The fully developed liver consists of five lobes: *right lobe, left lobe, quadrate, caudate,* and *spigelian lobes.* Five fissures: *umbilical, ductus venosus, transverse, gall bladder,* and *vena cava* fissures. Five ligaments: *ligamentum teres* (remnant of the umbilical vein), *falciform, coronal,* and two *lateral ligaments.*

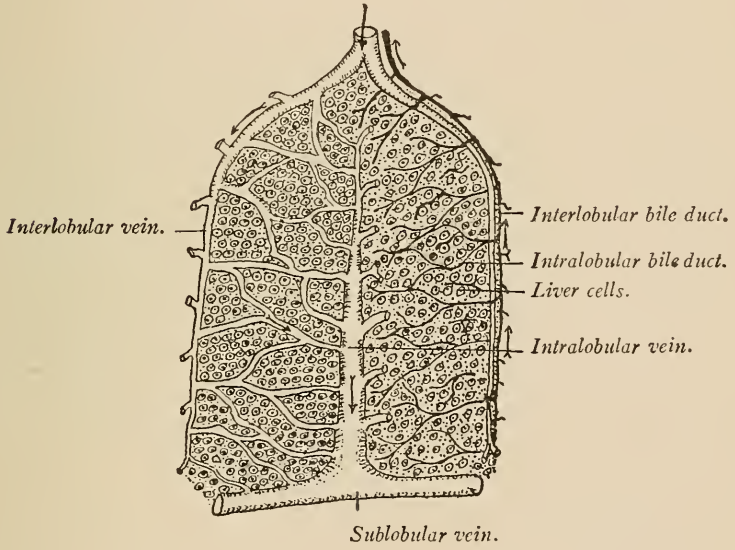


Fig. 163.—Diagram of liver lobule.

The description of these structures belongs to gross anatomy.

The liver is the largest gland in the body, weighing from three to four pounds, or one-fortieth the weight of the whole body. It measures ten to twelve inches in its transverse diameter, six to seven inches in its antero-posterior, and about three inches thick at the back part of the right lobe, which is the

thickest part. This heavy organ is held in position not only by its ligaments but by the abdominal pressure, and also by the connective tissue of the vena cava, which forms a dorsal fissure between the right and left lobes.

The organ is enclosed in a firm connective-tissue capsule (*capsule of Glisson*), which is very dense over the lower surface in the region of the fissures, par-

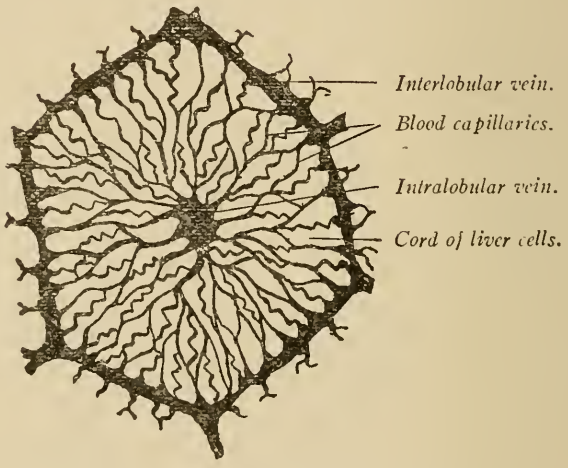


Fig. 164.—Injected blood-vessels in liver lobule.

ticularly the transverse, where the blood-vessels and bile duct enter. Septa from this capsule ramify between the lobes and lobules, and finer branches interlace between the liver cells, giving everywhere support and consistency to the organ. Here, as in every organ, blood-vessels, lymph-vessels, and fat are associated with this connective-tissue fabric. The capsule is closely invested with peritoneum, excepting a circular area bounded by the coronal ligament,

where the capsule, and therefore the liver, is in direct apposition with the lower surface of the diaphragm.

The blood supply of the liver consists of the *hepatic artery*, and a branch of the celiac axis, and the *portal vein*, formed by the junction of the splenic and superior mesenteric veins. The portal vein is by far the larger vessel. These vessels accompany the bile-

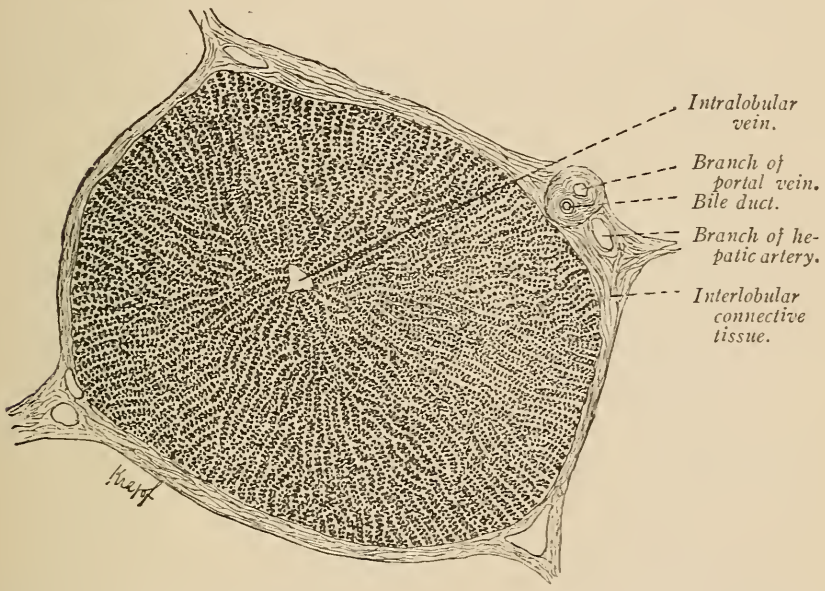


Fig. 165.—Section through liver of pig, showing chains of liver-cells (Böhm and Davidoff).

duct, and wherever one branches the others do, even to the finer terminations between the liver lobules. The duct, vein and artery form the ventral border of the *foramen of Winslow*. Their relation at this place is, bile duct to the right, artery to the left, and vein between and behind the other two. This relation is an important one in the surgery of these parts.

The Portal Canal.—This consists of an artery, a bile duct, and a vein, with accompanying lymphatics and connective tissue. Sections of the portal canal may be found between the liver lobules where the vessels are small, or between the liver lobes where the structures are large. The bile duct can be recognized by the columnar simple epithelium and the artery and vein by their respective histology. In

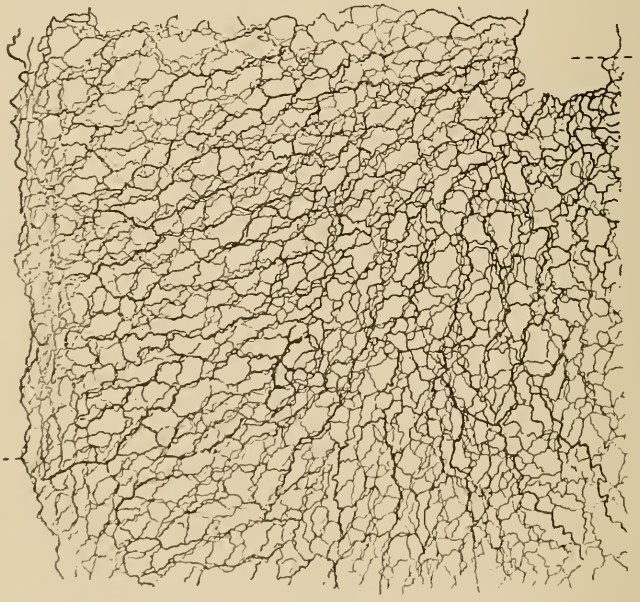


Fig. 166.—Reticulum (Gitterfasern) of dog's liver (gold-chlorid method) (Böhm and Davidoff).

pathological sections, where the lobules can no longer be recognized, the portal canal usually remains patent and is therefore a valuable criterion in the identification of this tissue.

The common bile duct is formed by the junction of the hepatic and cystic ducts at the mouth of the transverse fissure, and passes downward anterior to

the foramen of Winslow to open into the descending part of the duodenum three and one-half to four inches beyond the pylorus. It passes obliquely through the intestinal wall, where it is joined by the pancreatic duct, and opens by a common orifice on the bile papilla, as already described. The common bile duct is about three inches long and one-quarter inch in diameter.

The histology of the bile ducts resembles that of the gall bladder. There is on the inside a *mucous membrane* clothed with simple columnar epithelium resting upon a basement membrane. Smooth muscle cells are found in the membrana propria of the mucosa. The *submucosa* is a narrow vascular layer composed of connective-tissue elements. The *muscularis* consists of an inner circular layer and an outer longitudinal layer of smooth muscle. On the outside is a strong connective-tissue coat whose fibers are continuous with the capsule of Glisson.

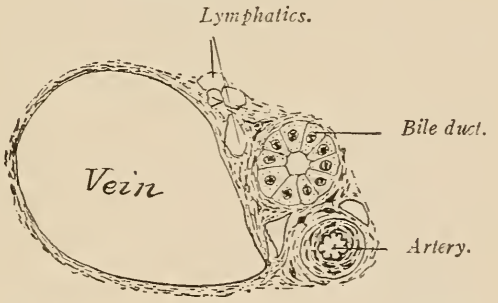


Fig. 167.—Section of portal canal of liver.

The passage of bile into the intestine is not a passive but an active process. The smooth muscle of the bile duct contracts in a peristaltic manner, and the bile is thus expelled into the intestine, periodically, in jets. This activity is normally under control of the nerves, largely a reflex action of the sym-

pathetic nerves associated with the intestine. If there is an obstruction to the free passage of bile, as in the passage of a calculus, the musculature of the ducts contracts violently and spasmodically, giving rise to the characteristic pain of plain muscle contraction described on page 94. If the obstruction occurs in the hepatic or the common duct, the liver becomes saturated with bile which is absorbed by the blood, and jaundice follows. If the obstruction is in the cystic duct the liver does not suffer and there is no jaundice.

Smaller Excretory Bile Ducts and Gall Bladder.—Small bile ducts of the liver begin within the liver lobules, where they form a complex system of anastomosing channels or tubes called *bile canaliculi.*

Interlobular Ducts.—The bile canaliculi unite to form *interlobular ducts* that lie between the liver lobules. These unite into larger and larger ducts and converge to pass out through the transverse fissure, where five or six ducts are found. The latter unite into two short *main ducts* that drain respectively from the right and left lobes of the liver.

The hepatic duct is formed by the union of the two *main ducts* at the bottom of the transverse fissure and thus receives the bile from the whole liver. It is from one to one and one-quarter inches in length and one-quarter inch in breadth, and extends downward from its origin, taking an irregular course, to its junction with the *cystic duct*, which unites with it to form the *common bile duct.*

The gall bladder, with its *cystic duct*, is an evagination of the bile duct. The gall bladder is a pear-

shaped receptacle for the retention of bile, and has a fundus, body, and neck. It is usually about three inches in length and one to one and one-quarter inches in diameter with a normal capacity of one to one and one-half fluidounces. Structurally it has an outer coat of peritoneum, a middle coat of connective-tissue elements, with a liberal mixture of smooth muscle fibers, and an inner coat of mucous membrane raised into folds and covered with simple columnar epithelium.

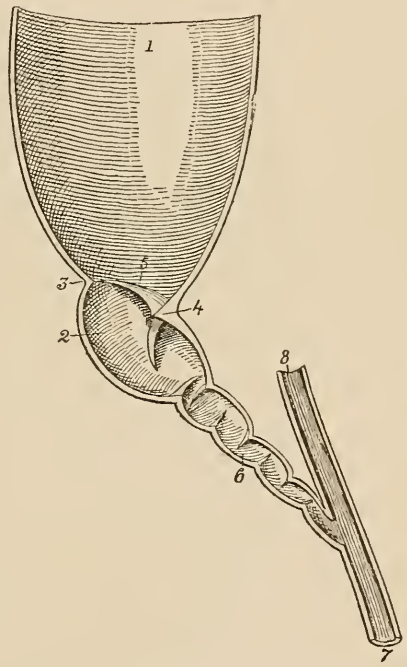


Fig. 168.—Portion of gall bladder and bile ducts: 1, Cavity of gall bladder; 2, cavity of calyx; 3, groove separating the calyx from the bladder; 4, promontory; 5, superior valve of calyx: 6, cystic canal; 7, common bile duct; 8, hepatic duct (Testut).

The cystic duct begins at the neck of the gall bladder and extends downward to its junction with the hepatic duct, with which it forms an acute angle. It takes an irregular course and is from one and one-quarter to one and one-half inches long; therefore longer than the hepatic duct, but only about one-half its diameter.

Liver Lobules.—These are minute units of the liver about the size of a pinhead. They are cylindrical

or irregularly polyhedral in shape, about 2 mm. in length and 1 mm. in breadth. Their arrangement is quite irregular except just beneath the capsule where they usually lie with their apices toward the surface. Each lobule has a connective-tissue investment in which the finer branches of the portal

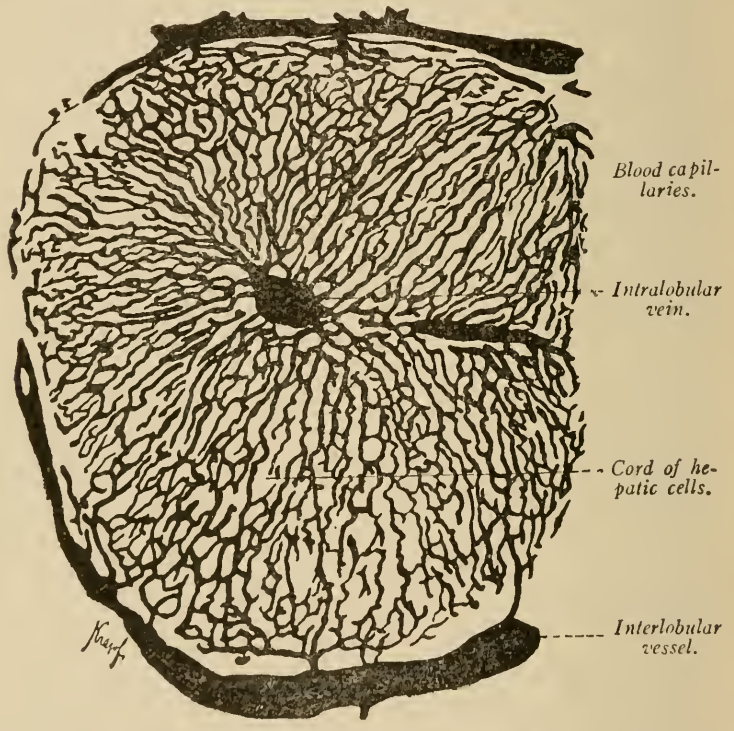


Fig. 169.—Injected blood-vessels in liver lobule of rabbit (Böhm and Davidoff).

canal ramify. This investment is particularly dense in the pig, which renders the organ in this animal very fibrous and tough, quite unfit for the market. In certain chronic liver diseases the same condition obtains, when the organ is spoken of as the "hob-nailed" or "nutmeg" liver.

In the center of each lobule is a blood-vessel known as the *intralobular vein*, while the small veins between the lobules are called the *interlobular veins*. These two sets of veins are connected by irregular blood capillaries that radiate from the periphery of the lobule to its center. They are typical capillaries whose walls consist of but a single layer of flattened

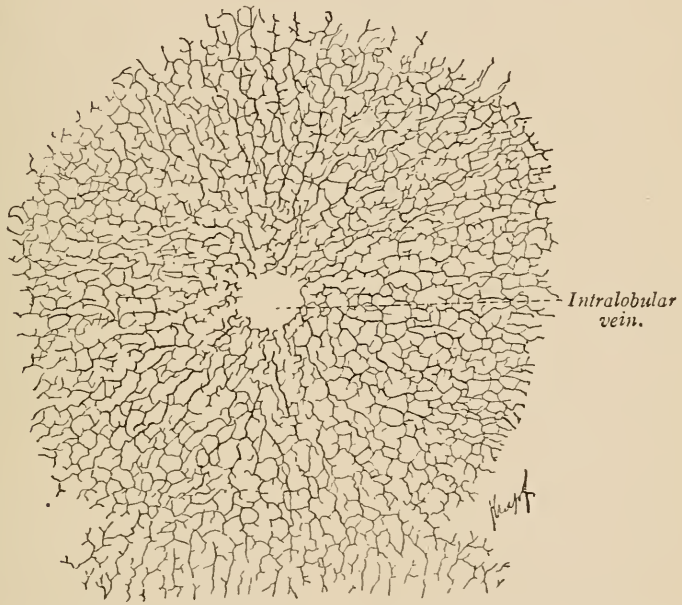


Fig. 170.—Human bile capillaries. The capillaries of one lobule are seen to anastomose with those of the adjoining lobule (below, in the figure) (chrome-silver method) (Böhm and Davidoff).

endothelial cells. The blood in the portal vein passes to the interlobular veins, then through the capillaries to the intralobular vein. The latter opens into *sublobular veins* which unite to form the *hepatic veins*, and these in turn open into the vena cava just below the diaphragm. The arterial blood of the hepatic artery supplies the connective tissues,

the walls of the bile ducts and blood-vessels, and doubtless some of this arterial blood finds its way into the liver capillaries where it blends with the venous blood from the portal vein.

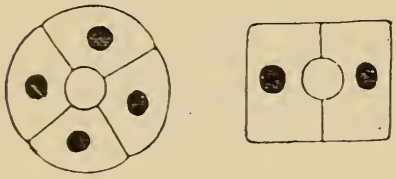


Fig. 171.—Schematic diagram of hepatic cord in transverse section. At the left the bile capillary is formed by four cells, at the right two; the latter type occurs in the human adult (Böhm and Davidoff).

From the center of each lobule toward its periphery irregular strands of liver cells radiate and freely anastomose with each other, as well as interlace between the blood capillaries. These are called *hepatic cords* and consist of double irregular rows of liver cells. The cords constitute the bile capillaries and unite at the periphery of the lobule with the bile ducts of the portal canal, situated between the lobules. The bile capillaries, therefore, are very fine tubes lying between the liver cells that constitute its walls. These tubes anastomose freely with each other and are the terminal endings of the bile passages or its secreting portions. The liver, as a

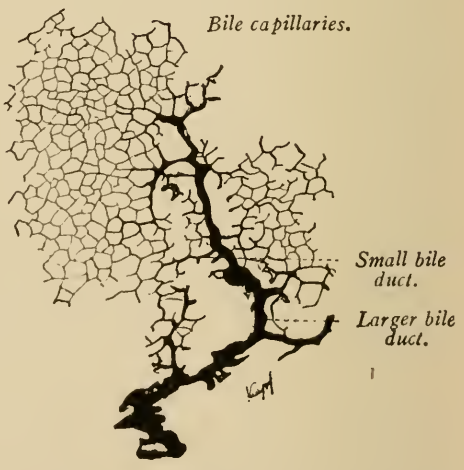


Fig. 172.—From the human liver, showing the beginning of the bile ducts (chrome-silver) (Böhm and Davidoff).

gland, thus differs from all other glands (1), that the secreting tubules anastomose, and (2) that the wall of the secreting portions consists of but two cells.

The liver cells have no cell wall. They are large polyhedral or irregular epithelial cells, containing sometimes two, but usually one, nucleus. The cytoplasm is granular, containing bile drops and vacuoles. The chief function of these cells is twofold: (1) to secrete bile into the bile capillaries, and (2) receive and contribute sugar to the blood capillaries. In junction with this it is affirmed that definite *cytoplasmic* or *intracellular* channels exist, particularly for the passage of bile. These channels end in minute dilatations within the cells, from which finer passages lead to and arborize around the nucleus. According to some investigators, the finer passages may penetrate the nucleus and are then called *intranuclear canals*.

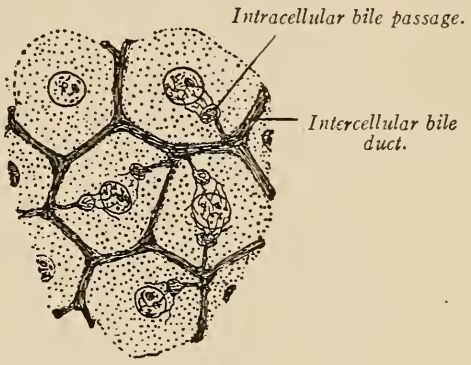


Fig. 173.—Diagram of liver cells, showing bile passages.

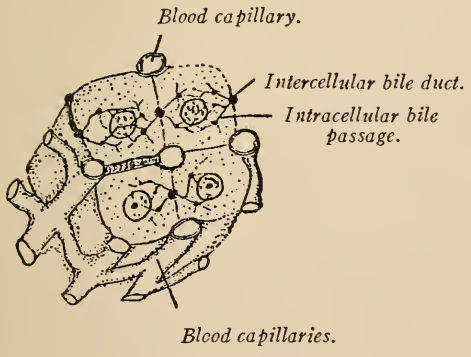


Fig. 174.—Diagram of liver cells, showing bile ducts and blood capillaries.

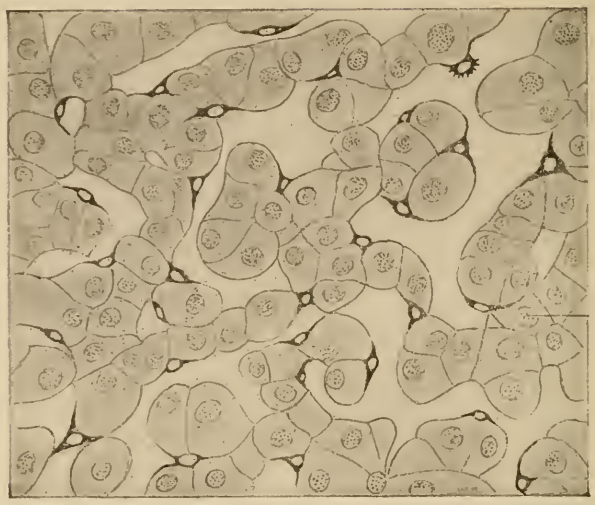


Fig. 175.—From preparation from the liver of a rabbit, showing the so-called stellate cells of Kupffer: *a*, Stellate cells; *b*, liver cells (Huber).

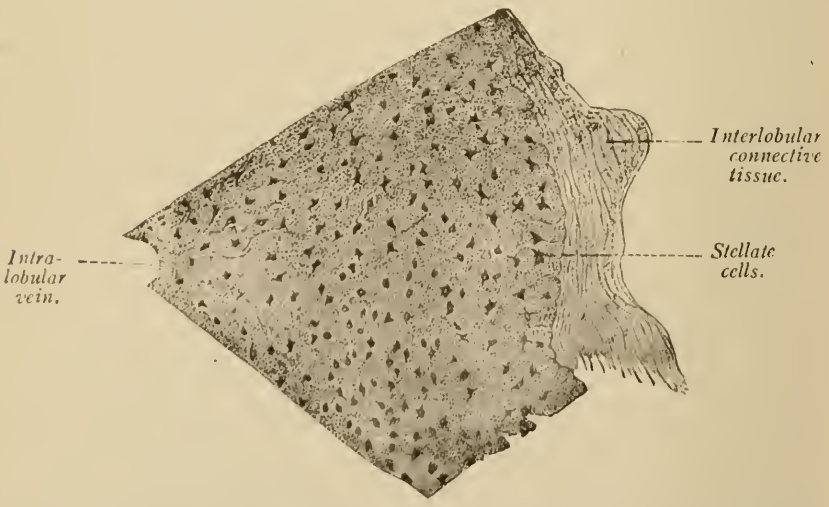


Fig. 176.—Part of a section through liver lobule from dog, showing stellate cells (Böhm and Davidoff).

Whether this intracellular system is an artifact due to manipulations or a normal condition is at present unsettled. In either case the liver cells play a delicate rôle, and a slight functional disturbance may allow the bile to escape to the blood capillaries, with jaundice as a natural sequel. In such a case there may or may not be any pain depending on the presence or absence of an obstruction in the bile duct.

Stellate Cells of Kupffer.—These are uniformly distributed in the lobules. The cells are irregular, elongated, and end in two or three pointed projections. They are smaller than the hepatic cells and are seen only after a special method of treatment. According to Kupffer these cells belong to the endothelium of the intralobular blood capillaries, and possess a phagocytic function.

Lastly, each lobule is interlaced by a fine reticular connective fabric that comes from the connective-tissue investment of the lobule. This gives support and consistency to the lobule.

Lymphatics of the Liver.—These may be divided into (1) the *interlobular lymphatics*, which accompany and in some places surround the blood-vessels, and (2) *subperitoneal lymphatics* on the surface of the organ which in the upper portions communicate through the ligaments with the thoracic lymphatics.

Nerves of the Liver.—The liver receives medullated fibers from the left pneumogastric and non-medullated fibers from the solar plexus. The nerves reach the organ between the two layers of the small omentum and accompany the portal canal, therefore enter the liver at the transverse fissure. The sympathetic

fibers innervate the walls of the blood-vessels. The medullated pass to the liver lobules where they lose the medullary sheath and then accompany the hepatic cords or bile capillaries to ramify ultimately between and around the liver cells.

CHAPTER VI.

ORGANS OF RESPIRATION AND THYROID GLAND.

The organs of respiration comprise the *larynx*, *trachea*, *bronchi* and *lungs*. More than forty per cent. of all deaths are directly due to diseases of this tract, which renders a thorough knowledge of this system of primary importance. These organs develop as a ventral median outgrowth of the fore-gut, and the mucous epithelium is therefore derived from the entoderm. The primitive connection with the alimentary canal is maintained in the adult, the upper extremity of the larynx opening on the anterior wall of the pharynx.

THE LARYNX.

The larynx in the male averages 44 mm. in length, 43 mm. transverse diameter, and 36 mm. antero-posterior diameter. In the female these dimensions are 36 by 41 by 26 mm. It is a cartilaginous muscular tube that contains the two *vocal cords*, the latter being transverse folds of mucous membranes.

In the wall are three single symmetrical cartilages, the *thyroid*, *cricoid*, and *cartilage of the epiglottis;* and three pairs, namely, two *arytenoids*, two *corniculæ laryngis* (cartilages of Santorini), and two *cuneiform*, making in all nine pieces. The two last pairs are very

small, while only the thyroid and cricoid are visible on the front and sides of the larynx. The cartilage of the epiglottis, the arytenoids, the corniculæ laryn-

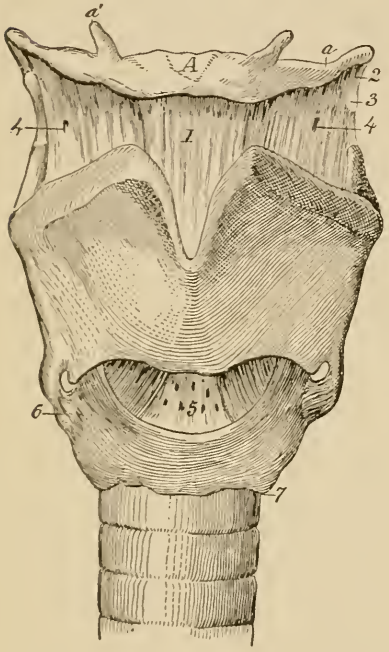


Fig. 177.—Articulations and ligaments of the larynx, anterior view: *A*, Hyoid bone, with *a* its greater, and *a'* its lesser cornua; 1–5, ligaments; 6, lateral cricothyroid articulation; 7, junction of cricoid and trachea (Testut).

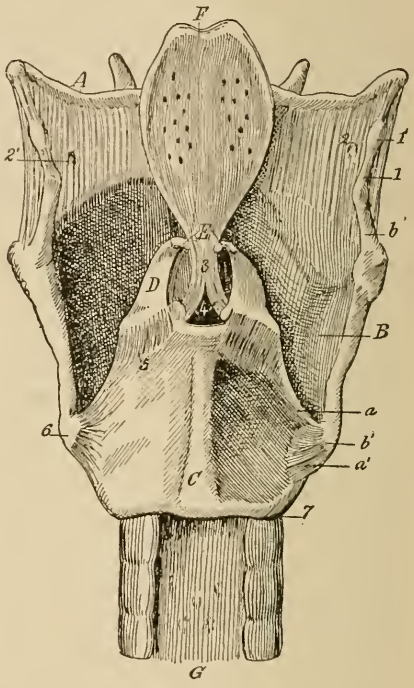


Fig. 178.—Articulations and ligaments of the larynx, posterior view: *A*, Hyoid; *B*, thyroid, with *b* and *b'* its cornua; *C*, cricoid; *D*, arytenoids; *E*, cartilages of Santorini; *F*, epiglottis; *G*, trachea; 1–6, ligaments; 2, opening for superior laryngeal artery; 7, junction of trachea and cricoid (Testut).

gis, are of the elastic or yellow fibrous variety and do not tend to ossify with age. The rest are composed of the hyaline cartilage, which tends to ossify with age. Many pairs of muscle control the manipulation of

these cartilages, regulating the vocal cords and modulating the voice.

The mucous membrane of the larynx is continuous

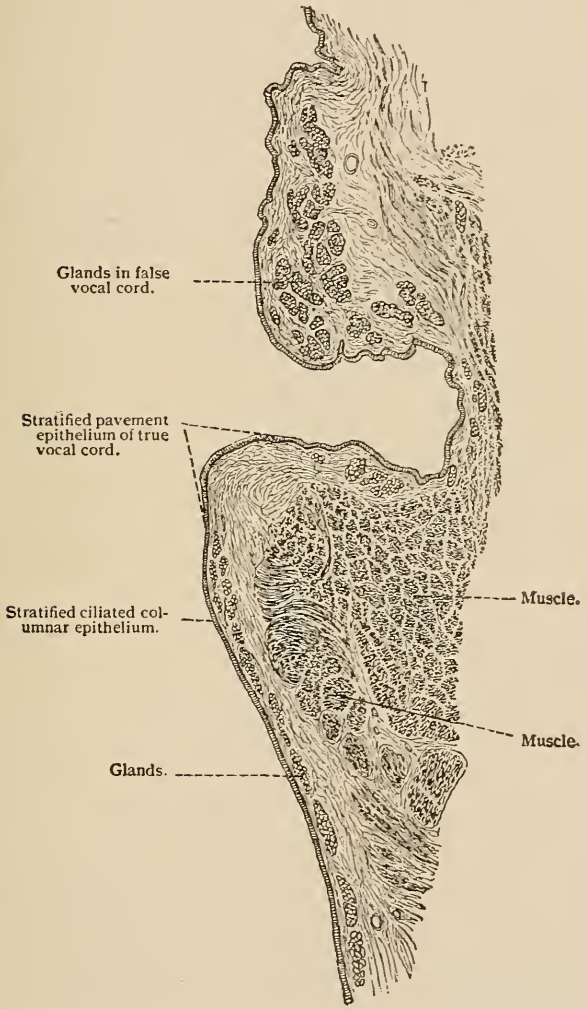


Fig. 179.—Vertical section through the mucous membrane of the human larynx (Böhm and Davidoff).

with that of the mouth and particularly sensitive about the upper part above the glottis. This mu-

cous membrane is covered in the greater part of its extent with stratified columnar ciliated epithelium. The cilia are found higher up the front wall than on each side, reaching in the former to the base of the epiglottis and at the sides to a point just above the false vocal cords. Above these points the epithelium is stratified squamous, like that of the pharynx. Upon the true vocal cords the epithelium is also stratified squamous. Mucous glands are found everywhere in this membrane but are particularly abundant upon the epiglottis.

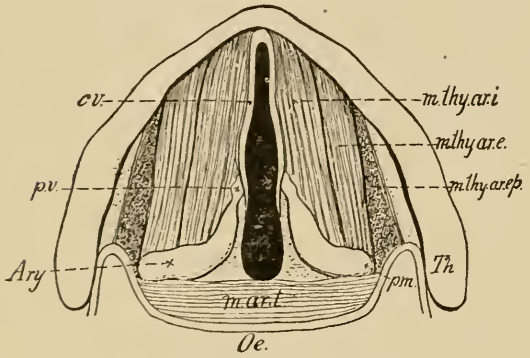


Fig. 180.—Diagram to illustrate the thyro-arytenoid muscles; the figure represents a transverse section of the larynx through the bases of the arytenoid cartilages: *Ary*, arytenoid cartilage; *p.m*, processus muscularis; *p.v*, processus vocalis; *Th*, thyroid cartilage; *c.v*, vocal cords; *Oe* is placed in the esophagus; *m.thy.ar.i*, internal thyro-arytenoid muscle; *m.thy.ar.e*, external thyro-arytenoid muscle; *m.thy.ar.ep*, part of the thyro-ary-epiglottic muscle, cut more or less transversely; *m.ar.t*, transverse arytenoid muscle. (Redrawn from Foster.)

The membrana propria, on which the epithelial cells rest, is not only very vascular but has a rich supply of elastic fibers and other connective-tissue elements. It is this tissue that becomes edematous and greatly swollen in infections, such as diphtheria. This is nature's method of eliminating the disease, with, however, the accompanying danger of suffocation.

The vocal cords are transverse elastic ligaments

covered with a very thin mucous membrane. They are attached anteriorly to the thyroid cartilage, close to each other, and diverge posteriorly to their attachment in the arytenoid cartilages. The *glottis* is the slit-like opening between the vocal cords.

THE THYROID GLAND.

The *thyroid gland* is not a part of the respiratory tract, but it is so closely associated with this tract in development and in position that it seems advisable to describe the organ in this place. The gland is a highly vascular body consisting of two *lateral lobes* and connected by a transverse bar, the *isthmus*. The rudiments of the lobes develop from the epithelium of the fourth gill cleft, while the isthmus and a large part of the lobes come from the floor of the mouth, the thyroglossus duct at the base of the tongue being a remnant of this origin. The gland is therefore an epithelial organ derived from the entoderm.

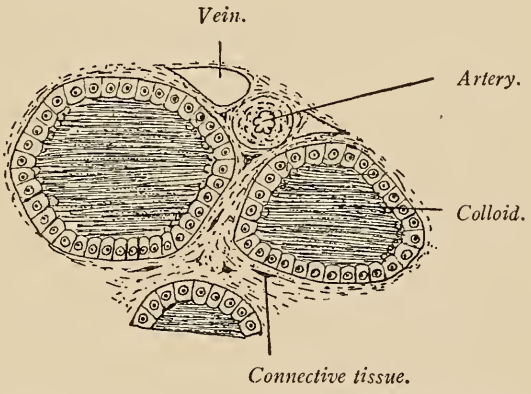


Fig. 181.—Section from thyroid gland, showing vesicles or alveoli.

In position the gland lies low down in the neck and in close apposition to the trachea. The isthmus crosses in front of the trachea and covers the second

and third cartilage ring. The lateral lobes are closely applied to the sides of the trachea and extend upward to cover the lower part of the thyroid cartilage. Each lobe measures about two inches in length, one and one-quarter inches in breadth, and one-half inch in depth. The gland, however, is subject to great variations both in size, form, and position. It is generally larger in females, and appears to undergo a periodic enlargement during each menstruation. It reaches its maximum growth at puberty, and is frequently much diminished in size in old age.

Fig. 182.—Portion of a cross section of thyroid gland of a man; *c*, colloid substance (Sobotta).

Structure.—The thyroid gland is invested by a thin layer of areolar tissue which not only binds it fast to the trachea, but divides it into small lobules of irregular size and form. It is a ductless gland consisting of epithelial vesicles varying in size from .05 mm. to 1 mm. in diameter. These vesicles vary greatly in form and are grouped and held together by areolar connective tissue in which many blood-vessels ramify. These vesicles are generally filled with *colloid substance*, a yellow viscid fluid, that in sections stains a yellowish red with eosin. They are

lined by a simple cubical epithelium made up of two kinds of cells, (1) a smaller number of *colloid cells* engaged in the production of colloid, and (2) intervening *chief cells* which replace the former in case they are lost. It is affirmed by some that the two kinds of cells represent merely different stages of secretion.

The thyroid, being an epithelial organ, may be the seat of a cancer. Goiter is a more common thyroid tumor, consisting of accumulations within its vesicles of colloid substance; or an increase of the connective-tissue elements; or a multiplication of the thyroid vesicles. Removal of the thyroid produces myxedema, while a congenital absence of the gland is the cause of cretinism. In the latter case, thyroid extract, regularly administered, will establish a normal growth of the child. In exophthalmic goiter the thyroid gland is enlarged, but in this case the enlarged thyroid is a symptom of a more general disease involving other organs and systems. The thyroid gland may be removed and grafted almost anywhere in the body. It will readily grow in its new position and assume its normal function with good results.

Vessels and Nerves.—The arteries of the thyroid gland are the *superior* and *inferior thyroid arteries* on each side, to which is sometimes added a fifth vessel, the *thyroidea ima*. The organ has, therefore, a very rich supply of blood. The smaller vessels and capillaries ramify in the connective-tissue elements between the gland vesicles. The veins, which are also large, form an extensive plexus near the surface of the gland, from which a *superior*, *middle*, and *inferior*

vein are formed on each side. Extensive lymphatics accompany the blood system. The *nerves* are derived from the *middle* and *inferior cervical* ganglia of the sympathetic. They accompany the blood-vessels, whose walls they innervate, sending also branches that extend close to the base of the epithelial cells.

PARATHYROIDS.

The *parathyroids* are two flattened bodies, one-fourth to one-half inch in diameter, that are con-

Fig. 183.—From parathyroid of man (Huber.)

stantly present and placed in close proximity to the upper and posterior surface of the lobes of the thyroid gland. They consist of solid masses of epithelial cells. Lymphoid follicles are usually closely associated with these masses. The function of these little bodies is not known; however, if the thyroid gland be removed and the parathyroid left, the effect of a complete thyroidectomy is not obtained.

THE TRACHEA AND BRONCHI.

The *trachea* extends from the cricoid cartilage, a point opposite the lower border of the sixth cervical vertebra, to the level of the intervertebral disc be-

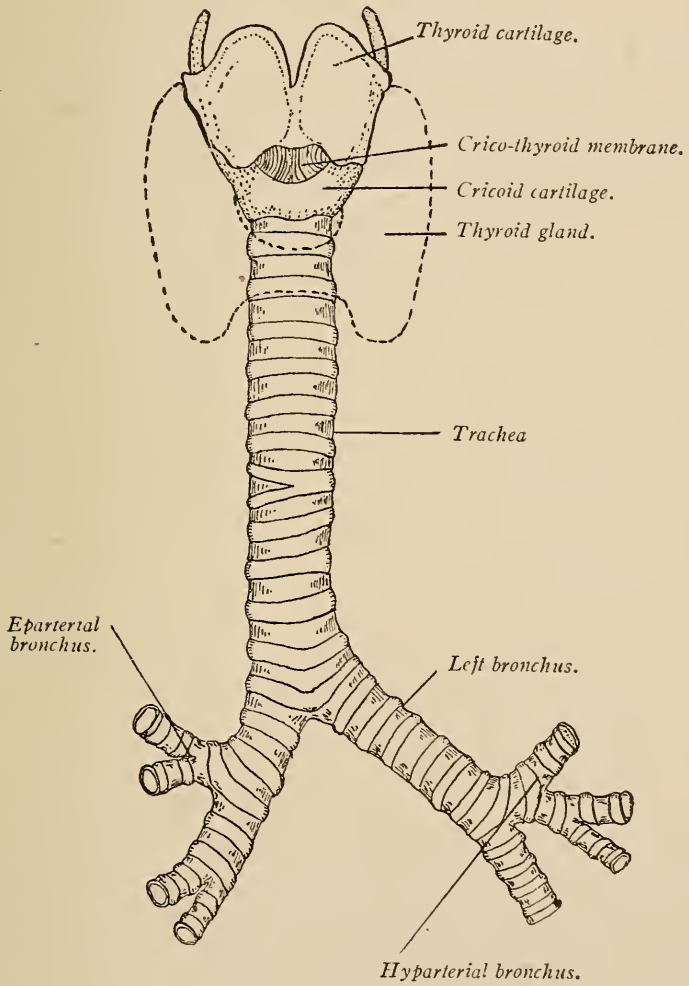


Fig. 184.—The trachea and bronchi.

tween the fourth and fifth dorsal vertebræ, extending therefore one to two inches into the chest. The

trachea measures from four to four and one-half inches in length, and three-fourths to one inch in width. It is smallest at its commencement, and, although quite uniform in its dimensions, is usually a little wider midway between its two ends.

At the lower end the trachea bifurcates to form the right and left bronchi, which pass each to the root of the corresponding lung. The right bronchus is larger than the left and more nearly vertical, so that in looking down the trachea more of the right than of the left bronchus can be seen. The right bronchus divides into branches, one to each root of the three lobes of the right lung, while the left gives off two branches, one to each lobe of the left lung.

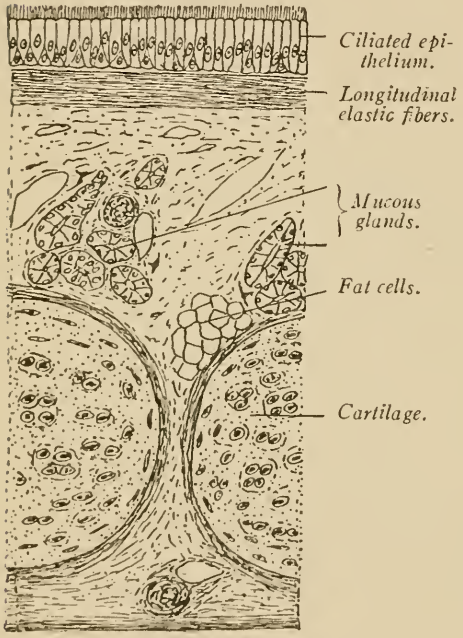


Fig. 185.—From longitudinal sections of trachea.

Structure.—In the wall of the trachea there are from sixteen to twenty C-shaped cartilage rings that make a little more than two-thirds of a circle. The outer surface of these cartilages is flat, but the inner surface is convex from above downward, so as to give greater thickness in the middle than at the edges. The cartilage is of the hyaline variety and is

enclosed in a periosteum. The cartilage rings are held together by a strong elastic fibrous tissue, which not only occupies the space between them but is prolonged over their surfaces, so that each ring appears imbedded in this tissue. Each cartilage terminates abruptly behind by rounded ends, between which

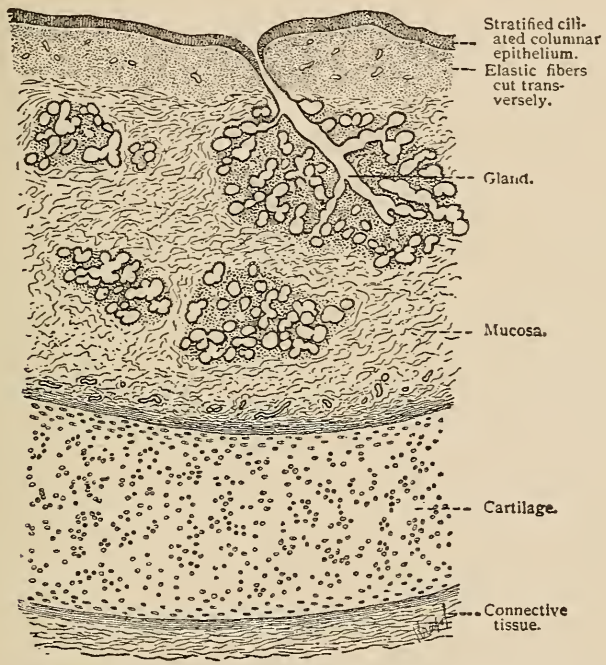


Fig. 186.—Transverse section through human bronchus (Böhm and Davidoff).

stretches a thin layer of smooth muscle tissue. This muscle not only unites the ends but is also found in the intervening space between the cartilage rings, along the posterior wall of the trachea. Outside of the transverse fibers are a few fasciculi having a longitudinal direction.

The cartilage rings of the bronchi resemble those

of the trachea in being incomplete behind. The right bronchus has from six to eight rings, while the left has from nine to twelve. The left bronchus is longer but narrower.

The *mucous membrane* is smooth and contains a considerable amount of lymphoid tissue and many mucous glands. The epithelial lining consists of long columnar ciliated cells, often very irregular and even branched at their fixed ends. One or two rows of small irregular cells intervene between the basal ends of the ciliated cells, and this epithelium is therefore stratified although very thin. The cells rest upon a basement membrane through which nerves pass to reach the sensitive epithelium. External to the basement membrane, in what constitutes the membrana propria, there is a strong layer of longitudinal elastic fibers. This tissue extends the whole length of the air passages, and gives not only great elasticity but is an obstruction to invading bacteria. A vascular submucosa, not very extensive, intervenes between the mucosa and the cartilage. In this may be found the bodies of small racemose mucous glands, the largest being in the posterior wall. The excretory ducts of these glands open on the inner surface. Lymphoid tissue is present both in the mucosa and the submucosa.

THE LUNG.

The *lungs* occupy the greater part of the chest cavity, of which they form an accurate mould. The right lung is the larger and has three lobes, while the left has two. Each lung is suspended freely in this

cavity and is attached only by a small part of its flattened or mesial surface called the *root*. The outer surface of each lung is covered by a serous membrane, the *visceral pleura*, which is reflected over the chest wall, where it is called the *parietal pleura*. The histology of the pleura is identical with that of the peritoneum.

Each lobe has one bronchus which divides rapidly into smaller bronchi. The latter, instead of having cartilage rings, are supplied with small cartilage plates. These plates are not present in bronchi whose diameters are less than 0.1 mm. Mucous glands are rather numerous but also disappear in bronchi less than 0.1 mm. in diameter. These smaller bronchi differ further from the larger ones in having a circular layer of smooth muscle that intervenes between the cartilage plates and the mucous membrane. The contraction of this muscle reduces the caliber of the smaller bronchi and thus regulates the amount of air that passes to the lung tissue. In asthma there is a spasmodic or more or less chronic contraction of this muscle tissue, which causes difficulty in breathing. The air is forced through the narrow tubes, and this brings about a dilatation of the terminal passages and a hypertrophy of the chest muscles, the latter being due to the forced efforts in securing sufficient air. Asthmatic patients, therefore, have resonant lungs and usually an enlarged chest. The primary trouble in this disease is not in this smooth muscle tissue, but seems to involve the nervous system and the innervating nerves. Smooth muscle is present in all the bronchi,

even in the smallest tubes whose diameters measure 0.2 mm.

Structure of the Lung.—The structure of the smaller bronchi, which form a part of the lung tissue, has just been described. Our knowledge of the terminal air passages has recently been greatly increased by the work of Dr. Miller, of the University of Wisconsin, whose account will be followed. The smallest bronchioles, whose diameters are 0.2 mm., are called *terminal*, or *respiratory bronchi*. In these

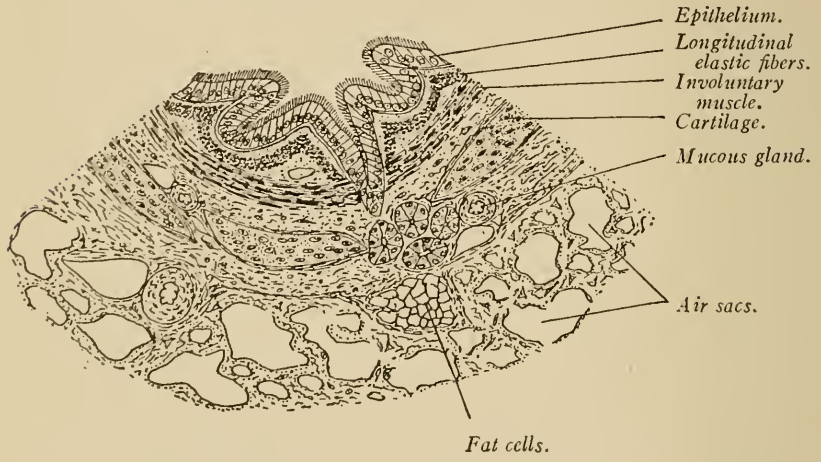


Fig. 187.—Section from lung showing portion of small bronchus and adjacent lung tissue.

tubes the character of the epithelial lining changes. Patches of small pavement epithelial cells appear among the ciliated cells, while at the end of the respiratory bronchus all are of the pavement variety. At this point the tube, slightly dilated, opens into three to six distinct chambers called *atria*. Each atrium opens into a variable number (2 to 5) of larger irregular spaces called *air sacs*, the walls of which have concave spherical depressions called *air*

cells, or *alveoli*. Simple pavement epithelium lines the atria and air sacs, consisting of two varieties of cells: (1) small nucleated elements, and (2) larger non-nucleated plates. The latter line the alveoli and are applied directly against the blood capillaries, while the nucleated elements intervene at the free margin of the alveoli. Before birth the air sacs are collapsed and all the pavement epithelium is composed of nucleated cells. With the first breath of air the air sacs become distended, not uniformly, but to form vesiculated walls, the small vesicles being the alveoli. The walls of the latter suffer greater distention, due to a less resistance offered by the opposing blood capillaries, and the nucleated cells in this region become changed to non-nucleated plates, through which an exchange of gases takes place during the functional activity of the lung. The atria and air sacs vary in size according to their distention with air. An average diameter is 1.0 mm. for the atria, and 1.0 by 1.5 mm. for the air sacs. Each air sac has from six to eight air cells, or alveoli, that also vary greatly in size, an average diameter being 0.25 mm. One system of atria and air sacs constitute a *lobule* and is separated from adjacent lobules by intervening areolar tissue. The base of each lobule is directed toward the surface of the lung and the apex towards its root. These lobules can be seen in a macroscopic surface examination of the lung.

The elastic fibers of the membrana propria, described in the wall of the trachea and bronchi, extend to the distal end of the air passages, where they spread out to form a thin reticular fabric just ex-

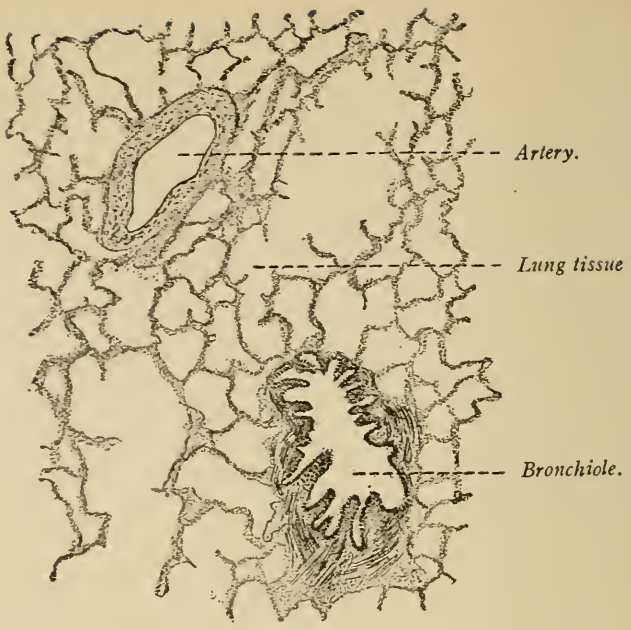


Fig. 188.

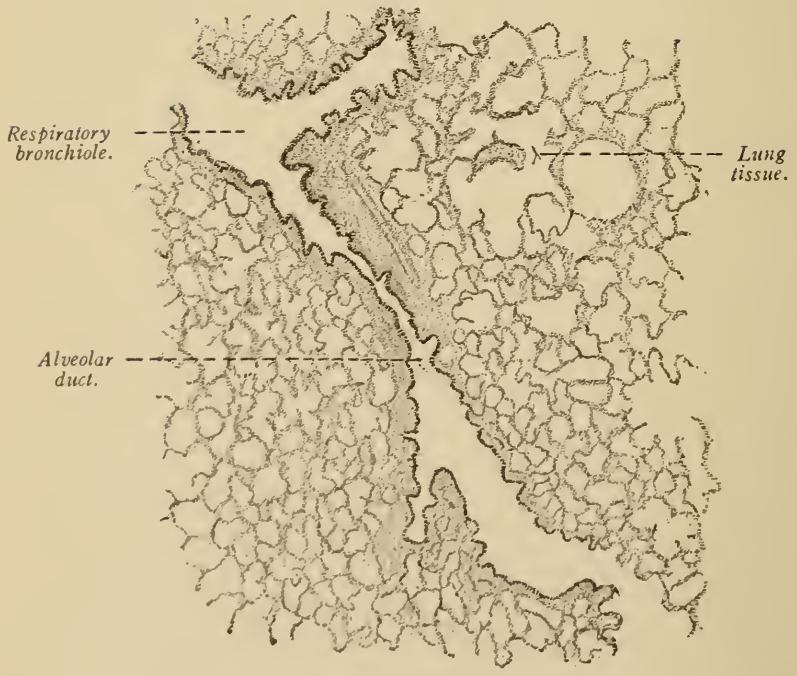


Fig. 189.

Figs. 188 and 189.—Two sections of cat's lung (Böhm and Davidoff)

ternal to the pavement epithelium, giving great elasticity to the air sacs and functions in the expulsion of air during normal breathing. The term *infundibulum* is sometimes applied to the distal air passage lined by pavement epithelium.

The following is a résumé of the tissues found in the walls of the respiratory passages:

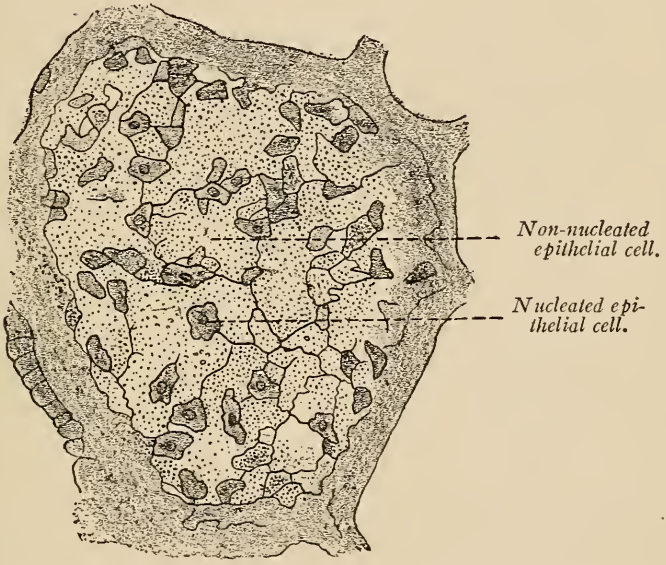


Fig. 190.—Inner surface of human alveolus treated with silver nitrate, showing respiratory epithelium (after Kölliker).

1. Epithelium extends the whole length. In the trachea and bronchi this is stratified ciliated. In the atrium and air sacs it is simple pavement and made up of two kinds of cells, namely, nucleated and non-nucleated.

2. Elastic fibers extend the whole length. In the respiratory parts the fibers form a reticulum just

external to the pavement epithelium and give elasticity to the lung tissue.

3. Mucous glands are found in the walls of the large passages down to tubes 1.0 mm. in diameter.

4. Cartilage is found in the trachea and bronchi down to tubes 1.0 mm. in diameter. In the trachea and larger bronchi the cartilage forms C-shaped rings, while in the smaller tubes the cartilage appears in plates.

Fig. 191.—Scheme of lung lobule (after Miller): *b. r.*, respiratory bronchiole; *d. al.*, alveolar duct (terminal bronchus); *a*, *a*, *a*, atria; *s. al.*, air sacs; *a. p.*, air-cells or alveoli.

5. Smooth muscle is found in the larger passages down to tubes 0.2 mm. in diameter, or down to the respiratory parts. In the trachea and the larger bronchi this muscle is placed in the posterior wall and between the ends of the cartilage rings. In the smaller bronchi it forms a circular layer between the lining epithelium and the cartilage plates.

Blood Supply.—The lungs, like the liver, receive blood from two sources, arterial blood through the *bronchial vessels*, and venous blood through the *pulmonary artery*. The *bronchial arteries*, from one to three for each lung, are much smaller than the pulmonary vessels, and carry blood for the nutrition of the lung. They arise from the aorta or from an

intercostal artery and follow the bronchial tubes through the lung, to be ultimately distributed in three ways: 1. They supply the bronchial lymph glands, the coats of the large blood-vessels, and the walls of the bronchial tubes, forming in the latter an outer and an inner plexus for the irrigation of the muscle coat and the mucous membrane. 2. They supply the interlobular areolar tissue; and 3, They spread out over the surface of the lung beneath the pleura. The *bronchial veins* do not have so extensive a distribution be cause some of the blood supplied by the bronchial arteries returns by the pulmonary veins. The superficial and deep set of bronchial veins unite at the root of the lung to drain on the right side into the large azygos and on the left into the left upper azygos vein.

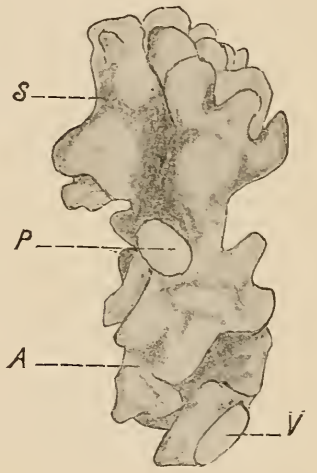


Fig. 192. — Reconstruction in wax of a single atrium and air sac with the alveoli: *V*, Surface where atrium was cut from alveolar duct; *P*, cut surface, where another air sac was removed; *A*, atrium; *S*, air sac with air cells (alveoli) (after Miller).

The *pulmonary artery*, which supplies the venous blood, is a very large vessel that gives branches to each lobe of the two lungs. The relation of the pulmonary artery to the bronchi is different on the two sides. On the right side the first branch of the pulmonary artery turns backward below the bronchus of the upper lobe, and then passes along the posterior

surface of this bronchus. On the left side the corresponding artery turns backward above the level of the first bronchial branch. The bronchus to the upper lobe of the right lung is therefore called an *eparterial bronchus*. All the other bronchi are below their respective arteries and are called *hyparterial bronchi*. Because of these relations it is believed that the upper lobe of the right lung has no homologue on the left side, and that the middle lobe on the right side is homologous to the upper lobe on the left. The pulmonary artery divides with the bronchi and closely accompanies them along their posterior or superior walls. The corresponding veins pass along the anterior or inferior walls. These blood-vessels are very large, often as large as the bronchial tubes, but in no case do they supply blood to the walls of the bronchi. At the apex of the pulmonary lobule, the pulmonary artery breaks up into several small twigs, one for each antrum, supplying blood to an extensive capillary plexus that spreads over the surface of atria and air sacs. The capillary meshes are very dense, and the capillary tubes very large, so that the intervening spaces are barely wider than the capillaries themselves. Because of the large size of the lung capillaries it is possible for fine

Fig. 193.—Section from injected lung showing capillaries of an air sac.

shreds from a blood clot, or emboli in the blood, to filter through and reach the left side of the heart by the pulmonary veins. If so, these emboli are quickly carried by the blood current around the aorta and up the right carotid, as the latter is the most direct route. This course takes them to the right side of the brain, in which the capillaries are narrow, and where the emboli lodge often with fatal results. Such emboli or shreds of blood clots primarily enter the venous system at the seat of a bone fracture, or in the walls of the uterus after parturition, or from clots of blood anywhere in the system.

The *pulmonary veins* carry blood from the pulmonary capillary plexus. Each venous radicle drains an area corresponding to several air cells or alveoli. At first these small veins take an independent course in the interlobular tissue, but after they have attained a certain size they accompany the arteries and the bronchi, and, as a rule, along the lower and front aspect of the latter. At the root of the lung there are formed two pulmonary veins on each side which open separately into the left auricle. The pulmonary veins have no valves, and unlike the veins of other organs are more capacious than their corresponding arteries.

Lymphatics.—The lymphatics of the lung are very extensive and accompany the two blood systems. We may therefore divide them into two sets, a *bronchial* and an *alveolar*. The *bronchial* consists of an elaborate, fine plexus that ramifies through the mucosa and submucosa of the bronchial tubes. This set anastomoses freely with a second plexus just ex-

ternal to the smooth circular muscle layer of the bronchi. Lymph nodes are interpolated everywhere in these plexuses. Just beneath the pleura, all over the surface of the lung, lymphatics ramify and drain toward the root of the lung, where they join the lymphatics located in the bronchial walls.

The *alveolar set* accompany the pulmonary vessels. These lymphatics have their origin in a plexus that surrounds the respiratory or alveolar portions of the lungs, and then accompanies the pulmonary arteries and veins along the external surfaces of the bronchial tubes to the root of the lungs, where they ultimately unite with the bronchial lymphatics. While lymphatic nodes are present everywhere, they are particularly abundant at the root of the lung. As tuberculosis spreads along the lymphatics, the different clinical aspects of this disease depend to a considerable extent on which of these systems becomes involved.

Nerves.—The nerves of the lung come from the pneumogastric and the sympathetic, and are made up of medullated and non-medullated fibers. They enter at the root of the lung and accompany the blood-vessels to the terminal air passages, where they arborize about the lung alveoli just external to the epithelial lining. Many nerve ganglia are located along their course and many fine fibers are given off that innervate the musculature and epithelial lining of the bronchial tubes and the walls of the blood-vessels.

CHAPTER VII.

THE URINARY ORGANS.

The following organs will be considered under this topic: *Suprarenal glands, Kidney, Ureter*, and *Bladder*. The *urethra* will be described in connection with the *generative organs*.

THE SUPRARENAL GLANDS.

The *suprarenals*, morphologically, belong to the nervous system, but their close proximity to the kidneys makes it advisable to describe them here. They are two triangular flattened organs covered with fat that lie one on either side of the spine, in close proximity to the upper kidney border. The left one is slightly larger and measures from one and one-fourth to one and one-half inches from above downward, one and one-fourth inches from side to side, and one-sixth to one-eighth inch in thickness.

Embryologically, the organs consist of a *cortical part* that develops in connection with the *Wolffian body* and therefore comes from the mesoderm, and a *medulla* which is associated with the *sympathetic nervous system* and is derived, at least in part, from the *ectoderm*. The medulla decomposes very rapidly after death, and the organ then resembles a capsule; hence the name, suprarenal capsule, is often used.

Each suprarenal is invested in a fibrous capsule and a liberal supply of fat. The capsule contains many elastic fibers and some smooth muscle cells.

The *cortex* shows a radial structure and has been divided into three zones, which are not very well defined.

1. The *zona glomerulosa*, next to the capsule, consists of a row of columnar epithelial cells folded in such a way as to form oval bodies or elongated heads separated by strands of connective tissue from the capsule. The oval nuclei are in the middle of the cells.

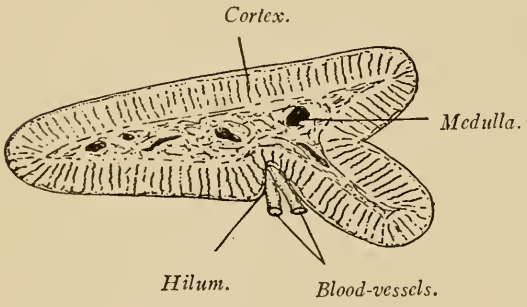


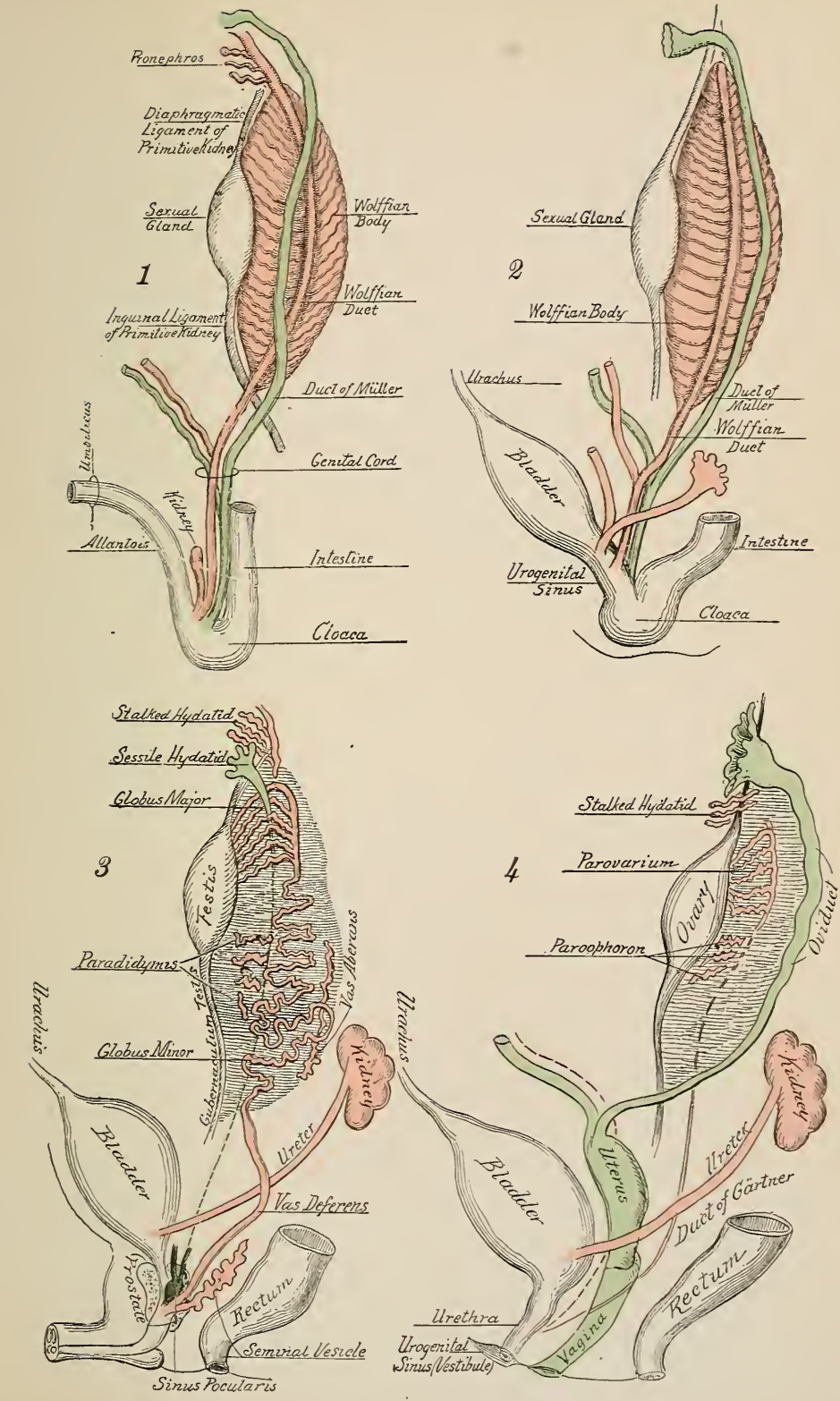
Fig. 194.—Cross section of suprarenal gland of man.

2. The *zona fasciculata* makes up the larger portion of the cortex and consists of anastomosing columns of epithelial cells, a continuation of the zona glomerulosa. Each column has two rows of polygonal cells that are smaller than those of the glomerulæ.

3. The *zona reticularis* borders on the medulla. Here the columns anastomose and freely interlace. The cells resemble those of the fasciculata. Connective tissue ramify between the columns, hence the radial appearance of the cortex.

The *medulla* is coarsely vascular. The cells are smaller than those of the cortex and are grouped in round or oval masses. These cells are finely granular, often pigmented, and stain a brown color.

PLATE IV


Pronephros
Diaphragmatic Ligament of Primitive Kidney
Sexual Gland
Wolffian Body
1
Wolffian Duct
Inguinal Ligament of Primitive Kidney
Duct of Müller
Genital Cord
Umbilicus
Kidney
Allantois
Intestine
Cloaca
2
Sexual Gland
Wolffian Body
Urachus
Duct of Müller
Wolffian Duct
Bladder
Intestine
Urogenital Sinus
Cloaca
Stalked Hydatid
Sessile Hydatid
Globus Major
3
Testis
Paradidymus
Vas Aberens
Urachus
Tunica Testis
Globus Minor
Kidney
Bladder
Gubernaculum
Ureter
Vas Deferens
Prostate
Rectum
Seminal Vesicle
Sinus Pocularis
Stalked Hydatid
4
Parovarium
Ovary
Oviduct
Paroophoron
Urachus
Kidney
Bladder
Uterus
Ureter
Duct of Gärtner
Rectum
Urethra
Urogenital Sinus (Vestibule)
Vagina

Numerous ganglion cells are present and many nerve fibers.

Blood-vessels.—Each suprarenal gland receives three arteries,—one each from the aorta, the phrenic, and the renal. The arteries break up into small branches, most of which enter the medulla through the hilum. Some branches ramify in the capsule

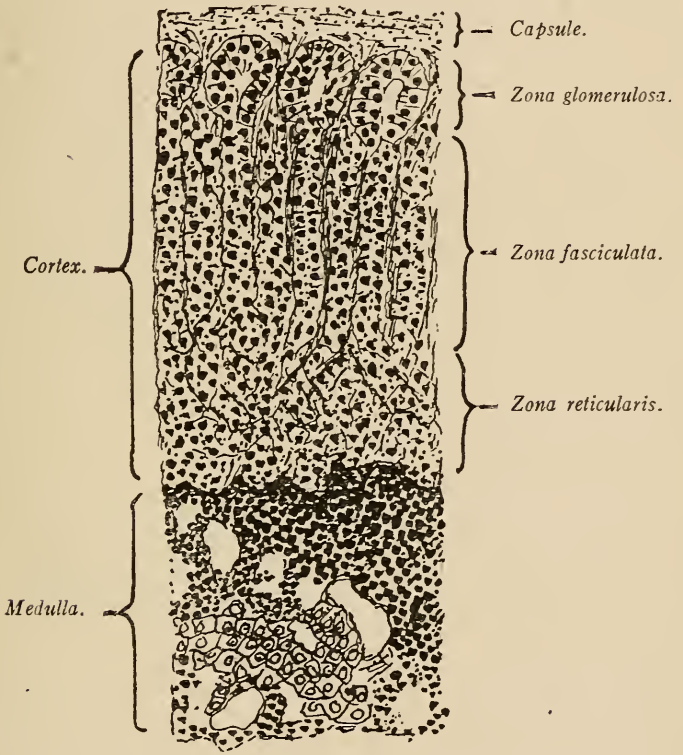


Fig. 195.—Section of suprarenal gland of dog.

and from there enter the cortex, where they form capillaries around the columns of epithelial cells. Those that enter the medulla form a coarse plexus in this part, and then send smaller capillaries into the cortex to anastomose with those from the capsule. The veins pass out from the center, usually one from

each organ. The vein from the right suprarenal enters the vena cava, while that from the left empties into the renal. Lymphatics accompany the blood-vessels.

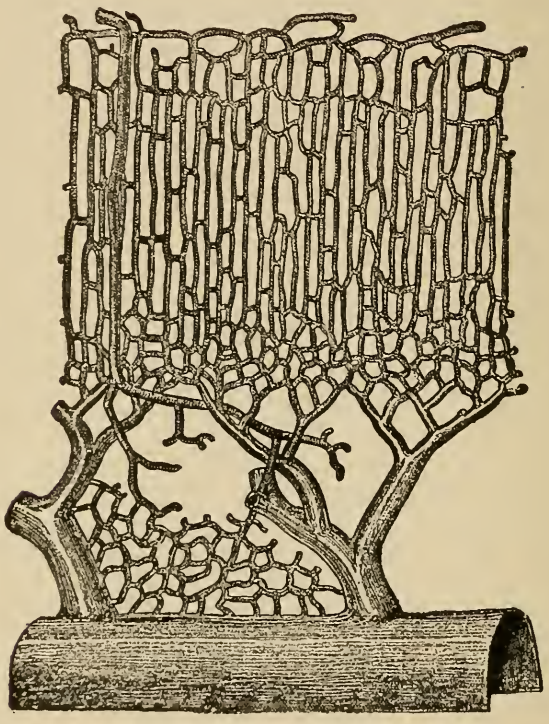


Fig. 196.—Arrangement of the intrinsic blood-vessels in the cortex and medulla of the dog's adrenal (Fig. 17, Plate V, of Flint's article in "Contributions to the Science of Medicine," dedicated to Professor Welch, 1900).

The **nerves** are exceedingly numerous and come from the solar and renal plexuses of the sympathetic, and medullated fibers from the phrenic and pneumogastric. They ramify freely among the ganglionic cells of the medulla and between the cells of the cortex, particularly those of the glomerulosa.

The function of the suprarenal gland is not known. Its extirpation in the dog is followed by death in a few days. There are at least three interesting clinical features connected with this organ:

1. Suprarenal extract, taken internally, increases arterial tension by contracting the small arterioles. The extract has the same effect when sprayed upon surfaces, therefore it is much used in nose, throat, and eye work, to check hemorrhage and reduce congestion.

2. The cortical cells may produce a malignant growth called a *hypernephroma*. The malignant cells may invade and replace the kidney. The growth usually spreads to the liver and adjacent organs, causing death in one to three years.

3. Addison's Disease is a chronic, usually tubercular, inflammation of the suprarenal glands, fatal in one or two years. It is accompanied with a striking bronze pigmentation of the skin, and digestive and nervous disturbances. It is a rare disease of middle life.

The above facts support the view that the organ secretes a substance that is regularly gathered up by the blood. This secretion may control, in a measure, arterial pressure. The organ is also a relay in the sympathetic nervous system which, when destroyed, as in Addison's Disease, accounts for the gastric and nervous symptoms.

THE KIDNEYS.

The *kidneys*, two in number, are compound tubular epithelial glands derived, embryologically, from the mesoderm. They are situated behind the peri-

toneum, one on each side of the vertebral column and on a level with the last dorsal and the upper two or three lumbar vertebræ. They are held in position by the renal vessels, by a loose areolar tissue that surrounds them which contains much fat, and by the abdominal pressure. Each kidney measures four inches in length, two and one-half inches in breadth, and one and one-fourth to one and one-half inches in thickness.

Their developmental history is rather complex and can be but briefly given here. It involves the history of the *pronephros*, *mesonephros*, and *metanephros*, three sets of excretory organs which replace each other in the sequence in which they are mentioned.

1. The *pronephros*, or *head kidney*, develops in connection with the *nephrotomes* of the first three or four embryonic somites. These nephrotomes unite with a longitudinal duct, the pronephric duct, which opens posteriorly into the cloaca. With this organ fluid from the celomic or peritoneal cavity can be eliminated, and also waste products from the blood, as a tuft of blood capillaries or *glomerulus* is present near the peritoneal opening of each nephrotome. This kidney is exceedingly rudimentary in mammals and functional only in larval stages of amphibians and in bony fishes.

2. The *mesonephros*, or *Wolffian body*, develops in connection with the *nephrotomes* posterior to those that form the pronephros. The pronephric duct becomes the *Wolffian duct* and drains from the peritoneal cavity in the same manner as in the head

kidney. The glomerulus in this case is situated in the wall of the nephrotome, which makes the mesonephros a more efficient organ. The mesonephros is an elongated segmented organ and a permanent structure in amphibians. It is an embryonic organ in birds and mammals, in which it is replaced by the metanephros.

3. The *metanephros, or permanent kidney,* develops as a diverticulum from the cloacal end of the Wolffian duct. The diverticulum lengthens into a tube, the ureter. The upper or anterior end of the tube

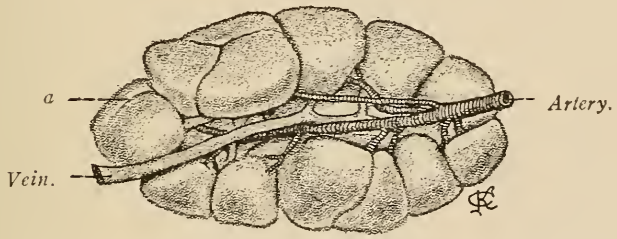


Fig. 197.—Kidney of new-born infant, showing a distinct separation into reniculi; natural size. At *a* is seen the consolidation of two adjacent reniculi (Böhm and Davidoff).

branches to form a number of smaller tubes, the uriniferous tubules of the kidney. The surrounding mesoderm becomes condensed and vascular, interlacing between the tubules to form the adult kidney.

The development of the urinary system is closely associated with that of the generative system, and will be referred to again when the latter is described.

Structure.—The *hilus* of the kidney is an opening through which the ureter and blood-vessels pass. On making a longitudinal section of the kidney, it will be seen that the hilus leads to an expanded fis-

sure, the *renal sinus*. The *pelvis* is a funnel-shaped expansion of the ureter that occupies a large portion of the sinus. The contents of the sinus may be removed, when the exposed wall will be found to be kidney substance.

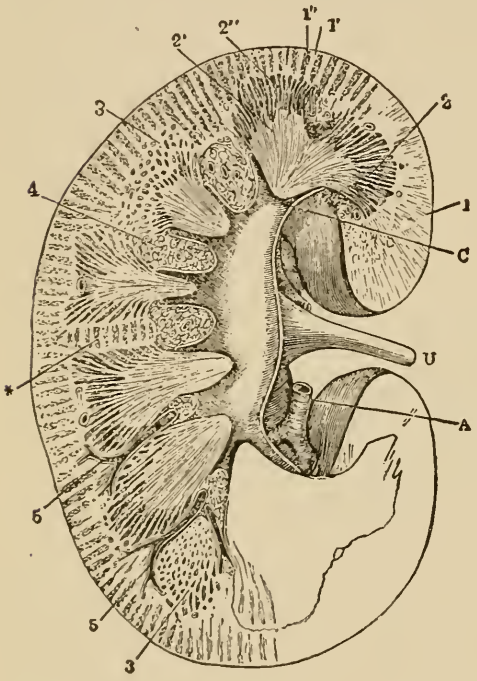


Fig. 198. — Longitudinal section through the kidney: 1, Cortex; 1′, medullary rays; 1″, labyrinth; 2, medulla; 2′, papillary portion of medulla; 2″, boundary layer of medulla; 3, transverse section of tubules in the boundary layer; 4, fat of renal sinus; 5, artery; *, transverse medullary rays; *A*, branch of renal artery; *C*, renal calyx; *U*, ureter (after Tyson and Henle).

Each kidney is enclosed in a smooth fibrous capsule of areolar tissue, a part of which also lines the sinus. The capsule is finely vascular and can easily be detached. If it adheres to the kidney substance it is evidence of disease.

It is customary to describe the kidney as made up of two layers, an outer, or the *cortex*, and an inner, the *medulla*, although there is no sharp line dividing the two. The medulla consists of ten or twelve separate conical masses called *Malpighian*, or *medullary pyramids*, so arranged that their bases border on the cortical layer and their apices point toward

the renal sinus where they form papillæ. The medullary substance is more dense than the cortical and is strictly striated, which is due to the radiating course of the tubules in this part. At the base of each Malpighian pyramid these tubules pass up into the cortical substance and are grouped to form cone-like masses called *medullary rays*, or *pyramids of*

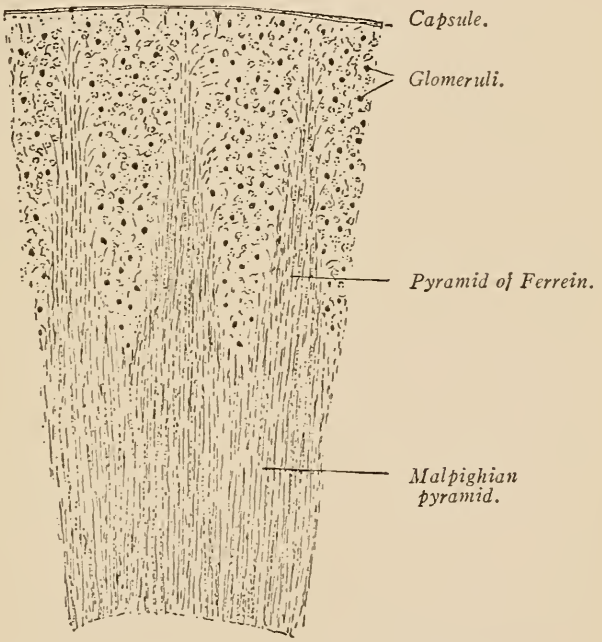


Fig. 199.—Section through cortex and medulla of kidney.

Ferrein, the apex of each being in close proximity to the periphery of the kidney. There are thus a great many medullary rays for each Malpighian pyramid. The portions of the kidney that intervene between the medullary rays are called the *labyrinth*, and consist largely of convoluted tubules. The cortical substance not only covers the bases of the

Malpighian pyramids, but sends prolongations between them down to the renal sinus. These cortical prolongations are called the *columns of Bertini*, of which there are as many as there are Malpighian pyramids.

It is convenient to describe the kidney tubules as consisting of nine parts. Each tube commences in the labyrinth of the cortex with (1) an invaginated dilatation called *Bowman's capsule.* This capsule is lined by simple squamous epithelium which, when invaginated, makes two layers, the lumen of the tube being between these layers. Into the invaginated cavity is crowded a tuft of blood capillaries called a *glomerulus.* A liberal supply of connective tissue blends with these capillaries. The capsule and glomerulus are frequently called a *Malpighian corpuscle.* At the base of the capsule each tube is constricted, forming (2) the *neck*, after which it becomes much convoluted and wide, forming (3) the *proximal convoluted tubule.* The cells of this part are large with very thin cell walls. The cytoplasm immediately around the nucleus is granular, but toward the basement membrane it is striated with lines at right angles to the membrane. The tube now approaches the medulla, becomes nearly straight, but rapidly narrows to form (4) the *spiral portion.* It now passes straight down a Malpighian pyramid, where it makes a short curve, and returning thus forms (5) the *loop of Henle.* This loop has a narrow descending limb with a short curve, and a wider ascending limb. The narrow descending limb and curve has simple

flat epithelium, so that the lumen is practically as

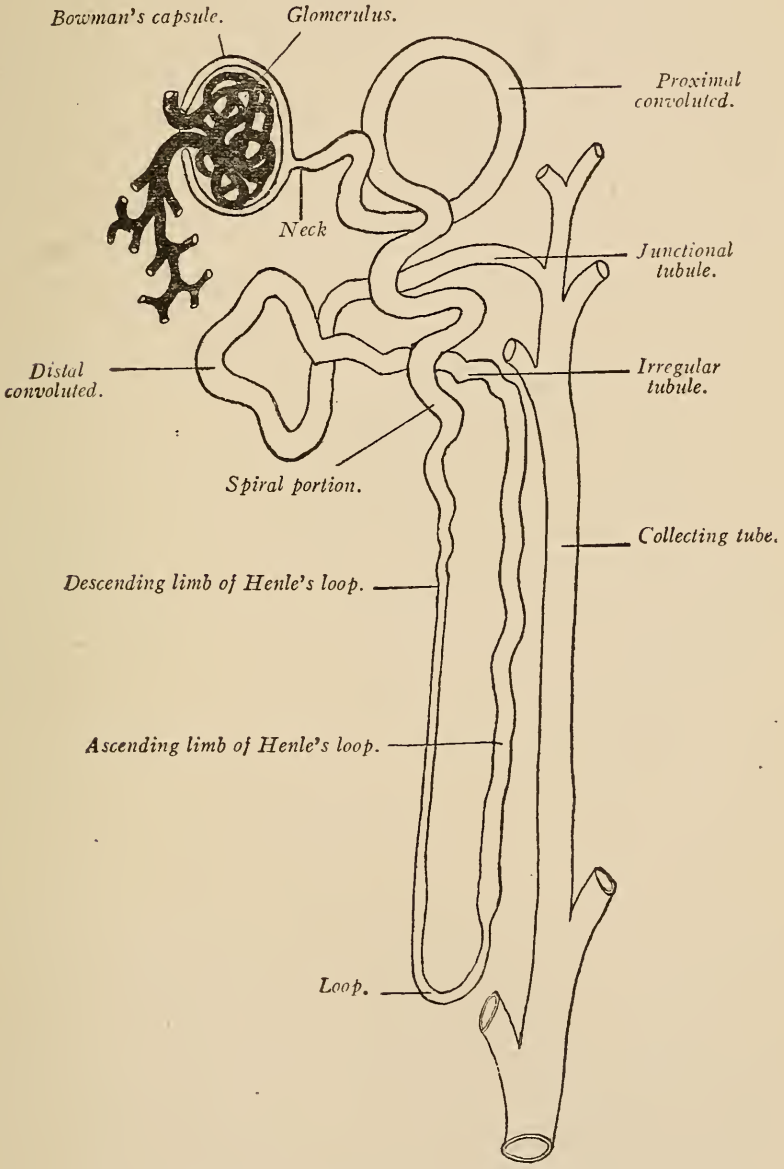


Fig. 200.—Diagram of kidney tubule.

large as that of the preceding part. The ascending

limb is larger but the epithelium takes on the characteristic of the proximal convoluted tube, although the cells are a little smaller and may contain pigment granules. The ascending limb passes straight up a medullary ray, from which it emerges to again enter the cortex, where it becomes irregular in outline forming (6) the *irregular tubule*, which quickly becomes much twisted and coiled to form (7) the *distal convoluted part*. In the irregular part the cells are very unequal in size and a rod-like structure of the cytoplasm is very distinct, while the basement membrane is said to be absent. The cells of the *distal convoluted tube* are rather long, with a distinct membrane and a highly refractive appearance of the protoplasm. Near the basement membrane minute projections from adjacent cells may be seen to interlock. Finally, this portion terminates in (8) a short *junctional tubule*, which leaves the cortex and enters a medullary ray to join the last part (9), the *collecting tubule*. The latter passes straight through the Malpighian pyramid to open on its surface in a small pore. In its course the collecting tube receives

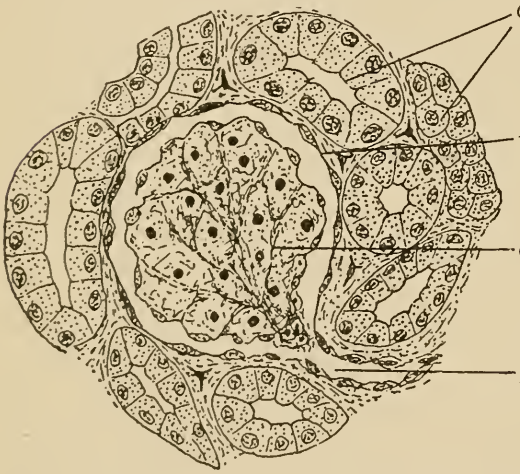


Fig. 201.—Section of a portion of the labyrinth of the kidney cortex.

not only other junctional tubules but also unites with other collecting tubes. The junctional part is narrow but its lumen relatively large, being lined by clear flat or cubical cells. The collecting tubes are large and have a lining of simple cubical epithelium.

The location of the different parts of the kidney tubules may be tabulated as follows:

Portion of Tubule.	*Location.*
1. Bowman's capsule	cortical labyrinth.
2. Neck	cortical labyrinth.
3. Proximal convoluted	cortical labyrinth.
4. Spiral portion	medullary rays.
5. Loop of Henle:	
(*a*) Descending limb	medulla.
(*b*) Loop	medulla.
(*c*) Ascending limb	medulla and medullary rays.
6. Irregular part	cortical labyrinth.
7. Distal convoluted	cortical labyrinth.
8. Junctional tubule	medullary rays.
9. Collecting tubule	medullary rays and medulla.

It will be observed that the walls of these tubules consist of simple epithelium; that this is made up of pavement cells in the capsule, neck, and descending limb of Henle's loop; while large cubical or columnar cells with granular and rod-like structure of the cytoplasm are found in the convoluted parts and ascending limb of Henle's loop; and a low cubical epithelium invests the junctional and collecting tubules.

Casts.—It is common in high fevers and in diseases of the kidney to find moulds of the uriniferous tubules in the urine. In high fevers blood may enter and congeal in the uriniferous tubules, the kidney secretion forces out this obstruction, which then appears in the urine as a *blood cast.* A clear serum mould is called a *hyaline cast.* In more chronic cases the cells of the tubules are carried away

and the mould is then called an *epithelial cast.* The cells may have decomposed, when it becomes a *granular cast.* Hyaline casts often show granulations and are then also called *granular casts.* Finally, fatty degenerations may appear and form *fatty casts.* The recognition and identification of casts form an important subject in clinical analysis. If small pieces of kidney are treated with strong hydrochloric acid and the detritus thus produced be examined in glycerin, under a low magnification, many pieces of the uriniferous tubules are readily observed. These pieces are practically identical with the epithelial and granular casts of the diseased kidney.

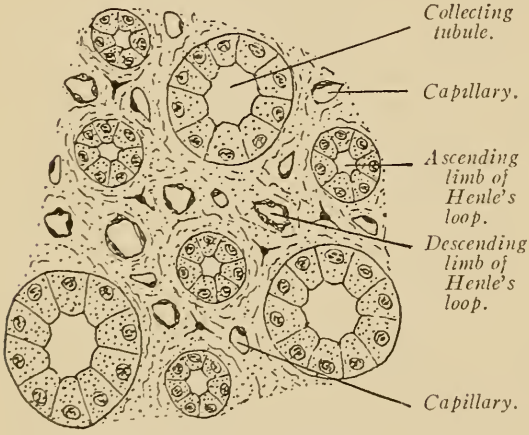


Fig. 202.—Section of a portion of a kidney medulla.

Blood-vessels.—The kidneys are highly vascular and receive a large amount of blood in proportion to their size. The renal artery and renal vein pass through the hilum, the artery between the vein and ureter. In the renal fissure the artery breaks up into four or five branches which lie external to the pelvis of the ureter. These branches pass directly to the columns of Bertini, where they break up into smaller vessels and rise to the level of the Malpighian pyramids. At this level they pass across the pyramids, between the latter and the cortex,

forming what are called *arterial arches*. The arteries form incomplete arches across the base of the pyramid, while the accompanying veins, in this place, form complete *venous arches* across the base of the pyramid. From the arches *interlobular arteries* pass outward between the medullary rays and among the convoluted tubules, taking a direct course toward the surface of the kidney. At intervals they give off curved short branches which pass directly to the glomerulus of a Malpighian corpuscle, where they break up into a spongy mass of capillaries. A vein, smaller than the artery, emerges from the glomerulus close to the point where the artery enters. The artery is called

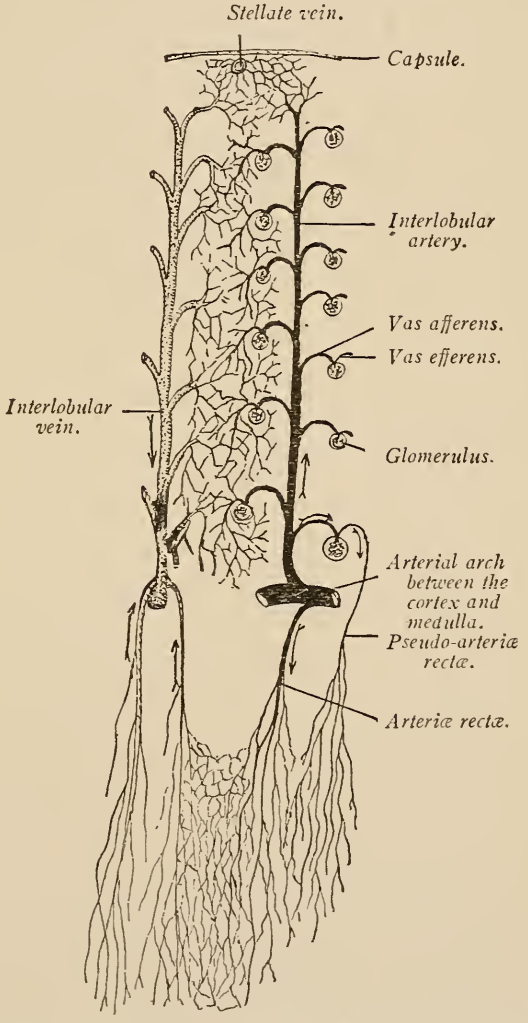


Fig. 203.—Diagram of blood supply of kidney.

the *vas afferens* and the smaller vein the *vas efferens*. The latter, instead of uniting with other veins to form larger trunks, as is the case in other organs, passes directly to the convoluted tubules, where it forms a dense capillary system that ramifies everywhere over the walls of these tubules. Many of the efferent vessels from the lowermost glomeruli, that is, those nearest the medulla, break up into pencils of straight vessels called *pseudo-arteriæ rectæ*, which pass directly into the medulla to form capillaries around the tubules of this part.

Interlobular veins convey the blood from the kidney cortex to the venous arches at the base of the pyramids. Near the periphery of the kidney other veins converge to form a stellate appearance just beneath the capsule. These *stellate* veins receive blood from the venous arches and also connect with the veins of the capsule.

The blood supply of the medulla is to a great extent independent of that to the cortex, excepting that supplied by the false arteriæ rectæ. Branches from the concave side of the arterial arches pass directly into the medulla, where they form bunches of pencils of small parallel vessels, the *arteriæ rectæ*, which supply blood to the walls of the uriniferous tubules of this part. Veins return this blood to the venous arches that lie between the cortex and medulla. These arches form veins that pass through the columns of Bertini and ultimately drain into the renal vein, which passes through the hilum to join the inferior vena cava.

On account of this extensive blood supply any renal disturbance is, as a rule, accompanied by a cor-

responding circulatory disturbance. Conversely, a disturbed circulation or an enlarged heart is indicative of a possible nephritis.

Nerves.—The nerve supply is derived from the cerebrospinal system and the sympathetic. Many of these supply the blood-vessels, which they always accompany, but some arborize among the renal tubules, particularly those of the renal cortex.

THE URETERS.

The ureters are two muscular tubes that conduct the urine from the kidneys to the bladder. The dilated commencement of each ureter is called the pelvis and lies with its base in the renal fissure, and extends through the hilum to the lower portion of the kidney where the ureter proper begins. Lateral expansions of this pelvis extend to and enclose the papillæ of the Malpighian pyramids, on the surface of which the collecting tubules open. These expansions are called *calyces*.

The ureters measure from fourteen to sixteen inches in length, and one-fourth inch in diameter. Each ureter lies behind the peritoneum and passes downward and inward to the brim of the pelvis, and then forward and inward to the base of the bladder. The ureters are about two inches apart as they enter the wall of the bladder, through which they pass obliquely for three-fourths inch to open on the inner surface in two narrow and slit-like openings. The oblique passage through the bladder wall acts as a valve to prevent a return flow of urine.

Structure.—The walls of the ureter consist of an

outer *fibrous*, a middle *muscular*, and an inner *mucous layer*. The latter has many longitudinal folds and is lined by transitional epithelium of four or five layers of cells. The superficial cells are flat, or low cubical, and may contain two nuclei. Their lower surfaces have depressions that fit upon the rounded ends of the second layer, which consists of oval or pear-shaped cells. Between the apices of the latter are two or three rows of small, irregular interstitial cells. Mucous glands have been described in the renal pelvis and so have lymphoid nodules, but the presence of glands in the ureter of man is doubtful. The membrana propria is composed of areolar tissue which becomes gradually loose toward the muscularis. This membrane is like others of its kind, having a limited blood supply. The *muscular coat* is composed of smooth muscle cells and consists chiefly of a circular layer between two thin longitudinal layers, particularly well defined in the lower part of the ureter. The *fibrous coat* is relatively thick and strong, contributing fibrous elements that interlace the muscle tissue.

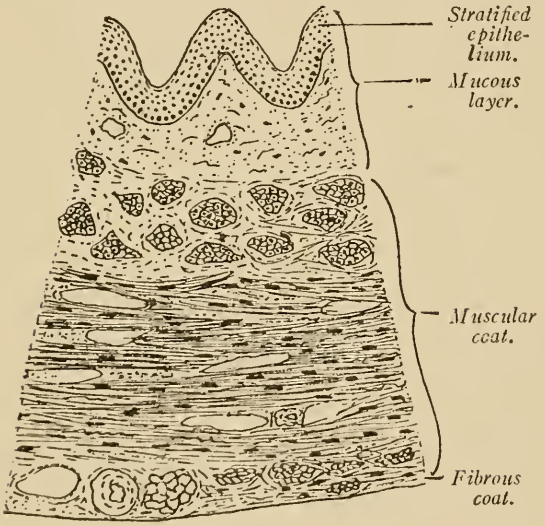


Fig. 204.—Cross section of the ureter.

The function of the ureter is an active one. A few drops of urine enter the ureter and are propelled along by the peristaltic contraction of its musculature, which forces the urine in intermittent jets into the bladder. In case of overdistention the force exerted by this mechanism is sufficient to rupture the bladder. In case of an obstruction in the ureter, as in the passage of calculi, a violent contraction of the smooth muscle follows, accompanied by severe pains. In surgical operations ureters have been sewed into the upper end of the bladder, or even into the intestine. In the latter case the kidney usually becomes infected with bacteria from the bowel.

THE URINARY BLADDER.

The urinary bladder is a receptacle for the retention of urine, with an average capacity of one pint, although capable of much greater distention. When empty it lies wholly within the pelvis, but if distended it rises into the abdomen. When moderately filled it has a rounded form, but when completely distended it becomes egg-shaped, the larger end, called the *base* or *fundus*, being directed downward and backward toward the rectum, and its smaller end, the *summit*, resting against the anterior abdominal wall. When distended the peritoneum covers the bladder, excepting a triangular space of two inches above the symphysis pubis known as the space of Retzius. This is of surgical importance, as the bladder can be opened through this space without going through the peritoneum.

The mucous membrane on the inner surface of the

bladder is loosely attached to the muscularis, and is slightly corrugated or folded in the contracted form of the organ. At the lower part of the bladder is found the orifice leading into the urethra, and immediately behind this is a smooth triangular surface called the *trigone*. The orifices of the ureters are found at the posterior angles of the trigone, and in the distended bladder are about one and one-half inches apart and about the same distance from the urethral orifice. When the bladder is contracted this space is diminished. An exact knowledge of these relations is important in any attempt to pass a catheter into the ureter.

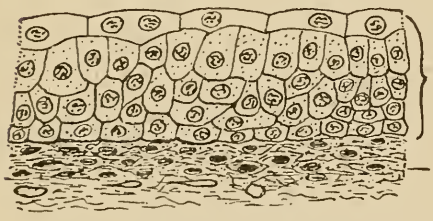


Fig. 205.—Section through the mucosa of the bladder.

Histology of the Bladder.—There is a mucous, submucous, muscular, and serous coat to the bladder. The *mucous membrane* resembles that of the ureters, with which it is continuous. It is covered with a transitional epithelium whose cells vary according to the distention of the bladder. As a rule, epithelial cells have but very little elasticity and mucous membranes, therefore are frequently much folded. The bladder cells are capable of considerable distention, when they become very flat. When the organ contracts they accommodate themselves to this condition and become cubical. The cells of the surface layer are squamous and have

concave depressions into which the rounded ends of the second layer or pear-shaped cells are adjusted. Two or more layers of irregular interstitial cells intervene between the apices of the pear-shaped cells. The interstitial cells divide regularly by karyokinesis and are then crowded to the surface to replace the superficial cells that normally exfoliate. There are no glands in the bladder, but solid cell projections are sometimes found that resemble glands. The bladder is a part of the *allantois*, a vesicular evagination of the hind-gut. The bladder epithelium, therefore,

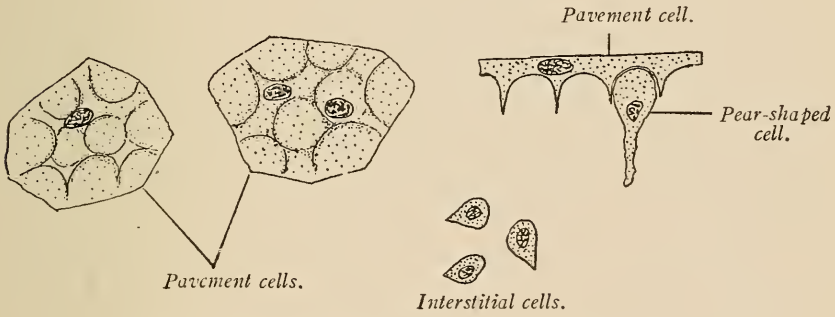


Fig. 206.—Epithelial cells from the bladder.

is of hypodermic origin, while that of the ureter is from the mesoderm.

A *vascular submucosa* intervenes between the mucosa and the muscularis. This is a thin layer of areolar tissue, but sufficient to give the mucosa apparent elasticity and enable it to move upon the muscularis.

The *muscular coat* consists of smooth muscle fibers which may be divided into bundles of outer longitudinal fibers, a middle strong circular layer, and an imperfect inner longitudinal or diagonal stratum.

At the urethral opening the middle layer is thickened to form a sphincter muscle, according to some authors. The bladder musculature forms a basket-work fabric, and when much distended intervals may arise in its walls which become points of weakness through which the mucosa may protrude, when the organ is said to be sacculated.

Vessels and Nerves.—The bladder is supplied with blood from the superior and inferior vesicle arteries, and in the female also from branches of the uterine artery. The veins form large plexuses, particularly around the neck, sides and base. They eventually drain into the internal iliac. The nerve supply is from the third, fourth, and sometimes the second sacral nerves, and from the hypogastric plexus of the sympathetic. The latter are nearly all non-medullated.

CHAPTER VIII.

REPRODUCTIVE ORGANS IN THE MALE.

Under this heading are included (1) the *testes* and their ducts, (2) *epididymis*, (3) *penis*, and (4) *prostate gland*.

THE TESTICLES.

The *testes* are two glandular organs for the production of spermatozoa, suspended in the scrotum by the spermatic cord. Each testicle is about one and one-half inches long, one and one-fourth inches wide, and nearly one inch thick from side to side. The corresponding dimensions of the ovary are, one and one-half by three-fourths by one-half inches.

The coverings of the testes are, (1) *skin*, (2) *dartos;* these two form the wall of the *scrotum*. The skin is thin and pigmented. The dartos is a reddish tissue continuous with the two layers of superficial fascia of the groin. It is vascular and consists of smooth areolar tissue and smooth muscle fibers. The latter give involuntary contractility to the scrotum and produce folds or rugæ in the skin. (3) *Intercolumnar fascia*, which is a thin connective-tissue layer closely associated with (4) the *cremasteric fascia*. The latter is continuous with the internal oblique muscle. (5) The *infundibuliform fascia* comes next and is a continuation downward of the fascia transversalis. (6) The *tunica vaginalis* envelops each

testicle and is derived from the peritoneum during the descent of the organ. It is therefore a serous coat that has the same histology as the peritoneum, and may be divided into two parts, one the *visceral portion* that invests the surface of the organ, and the other the *parietal portion* that is reflected over the surface of the infundibuliform fascia. The interval between these portions constitutes the cavity of the tunica vaginalis, and it is in this space that hydro-

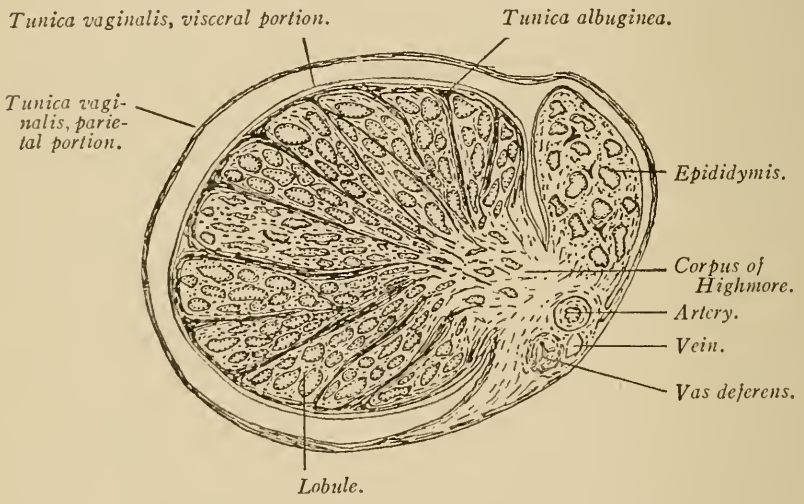


Fig. 207.—Cross section of human testicle.

cele fluid collects. (7) The *tunica albuginea* comes next and is a firm fibrous covering. This tunic sends fibrous cords or trabeculæ into the testis, which divide the organ into lobules. It is particularly dense along the posterior margin of the organ where it also invests the *vas deferens*, forming at this margin a mediastinum called the *corpus of Highmore*. (8) The *tunica vasculosa* is a delicate vascular layer that covers the inner surface of the

tunica albuginea. The three tunics just mentioned form the wall or capsule of each testicle, and are so closely associated that it is difficult to distinguish one from the other.

Structure.—The *testis* is a compound tubular gland divided into three hundred to four hundred lobules. Each lobule is conical in shape with the apex directed toward the mediastinum and the base toward the surface of the organ. The lobules differ in size according to their position. Each lobule represents several coiled tubules which, when unraveled, average two feet in length. There are at least six hundred to eight hundred of these tubules to each testicle. Their walls are lined with stratified epithelium which is invested with a thin layer of connective-tissue elements. The epithelium rests upon a basement membrane and may be arranged in at least three irregular groups or layers: 1. A layer of cubical cells, with small nuclei, rests upon the basement membrane. The cells of this layer are called *spermatogonia*. The *columns of Sertoli*, or *sustentacular cells*, also belong to this layer. These columns are elongated columnar cells that extend from the

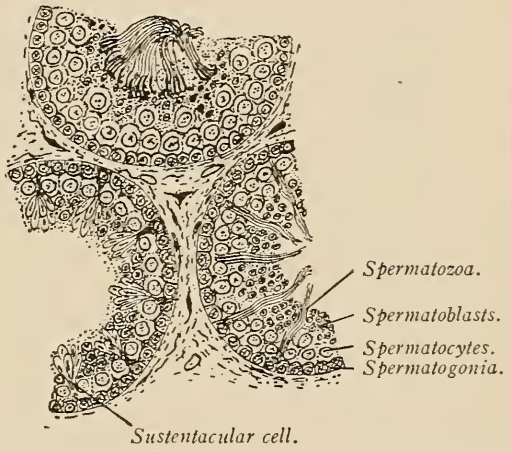


Fig. 208.—Section of convoluted tubules of testicle.

basement membrane inward toward the lumen of the tube. They give off lateral processes that form a reticulum about groups of young spermatozoa, to which they give both support and sustenance, according to the views of some authors. 2. Within the first layer there are one or two rows of large cells with large deep-staining nuclei. These are the *spermatocytes*. The latter multiply rapidly and continually to form, 3, *spermatoblasts* or *spermatids*. The spermatids are small spherical cells and each one in due time develops into a spermatozoön. The latter ripen regularly in groups which seem to cluster about individual sustentacular cells. The nucleus of the spermatids elongate and each little spherical cell gradually assumes the form of a mature spermatozoön. The different stages in this development can be worked out by a study of the spermatids as seen in the different tubules. In the cross section of a single tubule all the spermatids will be in the same stage of development. The spermatozoa when mature are crowded into the lumen of the convoluted tubules, where they mix with a viscid secretion which probably comes from the epithelial wall. The convoluted seminiferous tubules end blindly near the surface of the testis, where they are also said to anastomose with each other. In the other direction, each tubule becomes straight and forms the *tubuli recti*, which approach the mediastinum and function as excretory ducts. These erect tubules anastomose to form the *rete testis*.

Interstitial Elements of the Testis.—Like any other

organ the testicle has a fine reticulum of connective tissue that is associated with the capsule or tunica albuginea. This reticulum consists of areolar tissue that not only intervenes between the lobules, but interlaces between the seminiferous tubules. Blood and lymph vessels are everywhere associated with this tissue. In addition to ordinary connective-tissue cells, there is associated with this reticulum patches of cells that resemble epithelium and have yellowish granules or pigment. These are called *interstitial cells*, and, like the areas of Langerhans of the pancreas, are supposed to secrete products regularly absorbed by the blood. We can postulate a possible function of these cells when we consider the function of the testicle and its influence on the body as a whole.

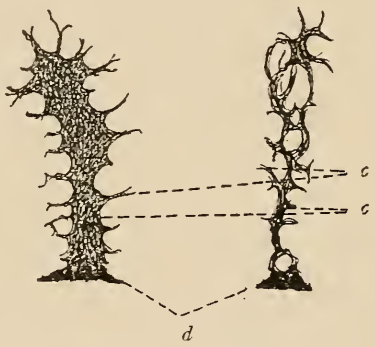


Fig. 209. — Sustentacular cells (cells of Sertoli) of the guinea-pig (chrome-silver method); profile view: *c*, *c*, Depressions in the sustentacular cells due to pressure from the spermatogenic cells; *d*, basilar portion of sustentacular cells (Böhm and Davidoff).

(1) Physiologically the testis exerts a marked influence on the development of the body. (2) It is actively engaged in the production of spermatozoa. (3) It is essential for the act of copulation.

Early castration in domestic animals is a striking evidence of the influence the testicle exerts upon development. The change manifest is both physical and mental. As the infantile testis does not

produce spermatozoa, it is believed that the secretions from the interstitial cells react upon the development of the body as a whole. While the seminiferous tubules function in the production of spermatozoa, it is not clear that the accumulation of semen prompts the sexual act. For instance, the testicles sometimes do not descend into the scrotum but remain in the body cavity. Frequently such testicles are of the infantile type, that is, no semen is developed; and yet the copulation act in such males is not only possible, but the sexual cravings may be actually exaggerated. The interstitial cells of such testicles are well developed and the male is otherwise normal. Again, the impotency that sometimes comes with old age is said to be due to impaired functional activity of the interstitial cells rather than to lack of spermatozoa. We have no specific medical treatment for such cases, extracts from normal testes having been tried without satisfactory results.

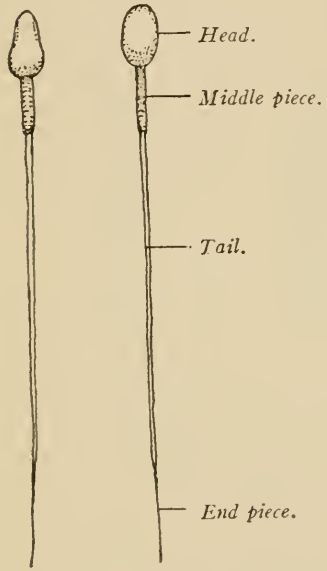


Fig. 210.—Human spermatozoa, side and flat view.

Spermatogenesis and Spermatozoa.—The development of spermatozoa begins in man in early youth and usually continues into old age. This phenomenon is in marked contrast to ovulation in woman, where there is a cessation or menopause at about the

age of forty-five. The explanation offered to account for this difference in the sexes is sought in the blood supply to the generative organs. There is a decrease in the nourishment to the ovaries as the menopause approaches, due to a contraction of the blood-vessels that supply the organ. The testes, on the other hand, have a liberal supply of blood throughout life.

The development of spermatozoa has been recorded with great accuracy, particularly in ascaris, insects, amphibians, and fishes, and there is little doubt but that the processes in mammalia are essentially the same.

The *spermatogonia* cells of the testicle after repeated division produce what are called *primary spermatocytes*. Each of the latter divides by somatic mitosis to produce two *secondary spermatocytes*, and these divide by *reduction mitosis* to produce *spermatids*, which, in turn, are moulded into individual *spermatozoa*. From every primary spermatocyte, therefore, four spermatozoa ultimately ripen, a detailed account of which will now be considered.

Multiplication of spermatogonia does not differ from other somatic mitosis. The primary spermatocytes, however, show a more condensed form of chromatin, and while the usual spireme structures develop, the chromosomes pair and fuse. This is not a chance fusion, but is said to be a selective union called *synapsis* of chromosomes. This coalition apparently reduces the chromosomes to one-half the original number. The synapsis is usually a collateral one, sometimes end to end, and while in most instances the union is complete, in other cases the double na-

ture of the chromosomes remains visible. Each paired chromosome now divides not only by splitting longitudinally, but also by a median transverse division, thus producing four fragments, each group of four fragments being known as a *tetrad*. The number of tetrads are thus equal to one-half the original number of chromosomes. The tetrad groups now arrange themselves in the equatorial plane of the

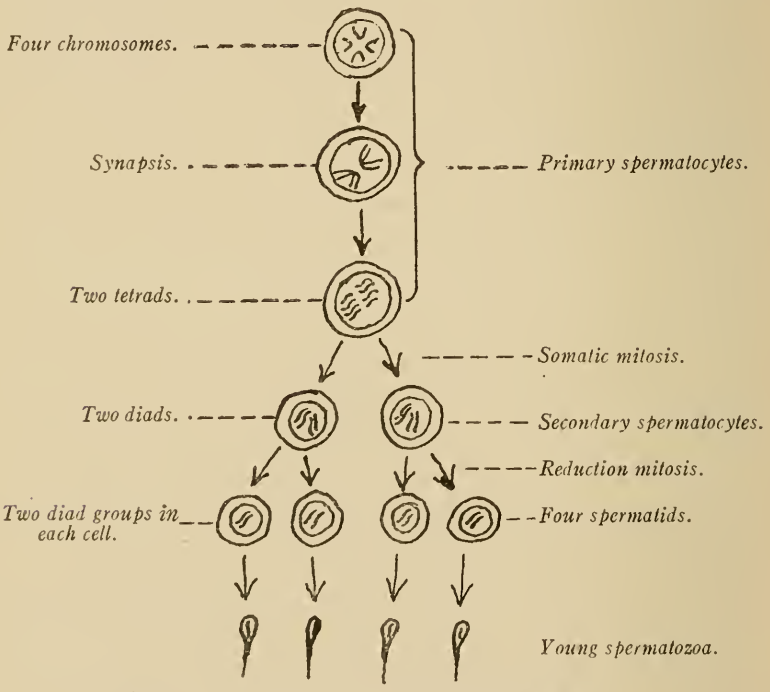


Fig. 210*a*.—Diagram of spermatogenesis.

spindle, and then two fragments or chromosomes from each tetrad pass to opposite poles of the spindle to form two daughter cells or the *secondary spermatocytes*. The chromosomes of each daughter cell, therefore, form in groups of twos instead of fours, and each group is now called a *diad*. The number of diads is equal to the number of tetrads,

and therefore equal to one-half the original number of chromosomes. A new spindle quickly forms in the secondary spermatocytes, the diads take an equatorial position and then separate to form *monads*, each daughter cell or *spermatid* receiving an equal number. The number of monads is equal to the number of diad groups and therefore equal to one-half the original number of chromosomes. The division of tetrad groups to form diads is usually considered an *equational* or somatic process, while the division of the diad groups to form monads is looked upon as a reduction process. The splitting of the tetrads is then interpreted as a longitudinal division of the chromosomes, and that of the diads as an end-to-end division. Each spermatid ultimately moulds to form ripe *spermatozoa* and thus every primary spermatocyte produces four spermatozoa.

Sex Determination.—Cytological and experimental work in recent years have revealed facts which show that certain chromosomes play an important part in the determination of sex. In the grasshopper (Stenobothrus viridulus) the cells of the male have seventeen and the cells of the female eighteen chromosomes. In case of the primary spermatocytes, each with seventeen chromosomes, when synapsis occurs, one chromosome is left without a mate. This odd one is called the *accessory chromosome*, and can be recognized by its condensed form, heavy staining qualities, and its position near the nuclear membrane. When the primary spermatocyte divides, this accessory or univalent chromosome remains undivided within one of the daughter cells, thus mak-

ing two kinds of secondary spermatocytes. When the latter divide the accessory chromosome also divides, thus giving rise to two kinds of spermatozoa in equal numbers, one-half of them having eight and one-half nine chromosomes. The *mature* ova have no such complications, and each one has nine chromosomes. When fertilization takes place two combinations are possible. Should a spermatozoön with eight chromosomes fertilize the egg, then a male develops with somatic cells that have seventeen chromosomes, and if one with nine is used, then a female is produced with somatic cells having eighteen chromosomes.

In some cases the accessory chromosome has a small mate in synapsis. Two classes of spermatozoa develop, one-half with a large and the other half with a small chromosome. The class with the large chromosome produces females, and that with the small produces males.

Two kinds of spermatozoa, differing in quality and quantity of chromatin material, have been described in the whole animal phylum, even in man, and it seems to be proved that the quality of the spermatozoön in these forms determines the sex. But there are many forms of life, particularly in plants, where parthenogenetic and other asexual development prevail and where sex cycles arise from factors other than spermatozoa. In some of these the quantity and quality of food are sex factors, while in others we do not know the determining agents.

Structure of Spermatozoa.—A spermatozoön is a minute cell, about 0.055 mm. long and consisting of a *nucleus* or *head*, a *middle piece* or *body*, and a vibra-

tile *tail*. In man *the head* is a flattened ovoid, appearing pear-shaped or pointed in one view and rounded in another. It contains the nucleus and stains heavily with nuclear dyes. It measures about 0.0045 mm. long, 0.0025 mm. broad, and 0.0015 mm. thick.

The *middle piece*, or *body*, is cylindrical in man, and measures about 0.006 mm. in length, and 0.001 mm. in thickness. In some animals, as the rat, a spiral thread can be seen coiled about the periphery, whilst through its center a slender filament seems to pass and be continuous with the central filament of the tail. This filament ends in a terminal enlargement placed in close proximity to the nucleus and known as the *terminal globule*.

The *tail* is about 0.045 mm. long and tapers toward the extremity, ending in an extremely delicate fiber, the *end piece*. Again, in the rat this end piece seems to be the terminal part of the central filament of the middle piece, which thus extends the whole length of the tail. The spermatozoön is propelled forward by a spirally lashing movement of the tail, similar to the movement of cilia. Movement of cilia, however, ceases as soon as they are removed from their cell, which is not the case with the tail of a spermatozoön, in which motion seems to be an intrinsic quality. So long as spermatozoa remain in the male passages they are inert, but become active as soon as expelled.

Spermatozoa differ a great deal in the different species of animals. They are very hardy cells, and in the female passages may live for days and even weeks. In some domestic birds, as turkeys, they

live at least a month, while in bats copulation takes place in the fall and fertilization follows in the spring.

Excretory Ducts of the Testis.—These ducts are the tubuli recti, rete testis, vasa efferentia, epididymis, and vas deferens.

Tubuli Recti.—The seminiferous tubules, towards the mediastinum, unite at acute angles to form a

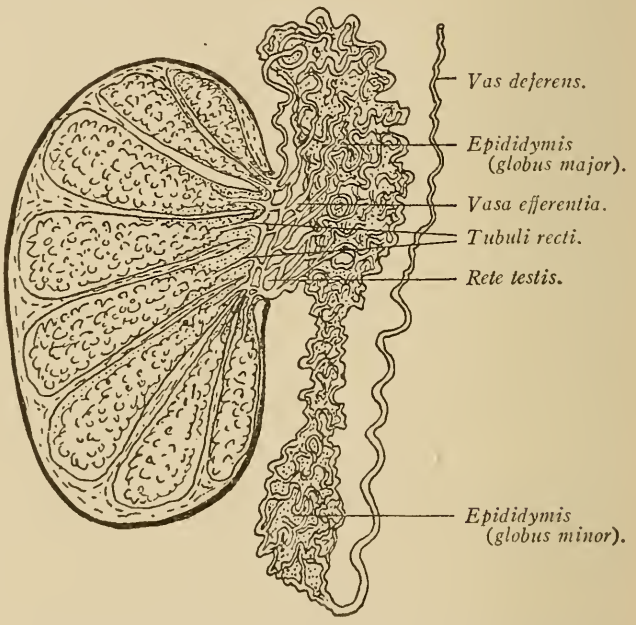


Fig. 211.—Diagram of human testicle, longitudinal section.

series of short parallel straight tubes called the tubuli recti. They are clothed by a simple layer of low cubical epithelium.

The *rete testis* consists of a reticulum of tubules formed by an anastomosis of the tubuli recti in the mediastinum. They are lined by simple columnar epithelium.

The *vasa efferentia* are tubules that lead from the

upper portion of the rete testis through the tunica albuginea to the epididymis. There are about fifteen of them. They are lined by simple columnar ciliated epithelium, and represent tubules that embryologically belong to the mesonephros. Outside of the epithelium is a thin investment of areolar tissue in which smooth muscle cells interlace.

The *epididymis* is a very much coiled canal, about twenty feet long, formed by the confluence of the vasa efferentia. At the upper and posterior border of the testis the vasa efferentia and epididymis form a globular mass of tubules called the *globus major*. At the lower and posterior border there is a smaller mass of coiled tubules formed by the epididymis, and called the *globus minor*. The epididymis is lined by simple epithelium which is ciliated in most places, but interposed are patches of nonciliated cells. The latter form small areas that resemble glands. External to this epithelium there is a thin layer of smooth muscle fibers which blends with vascular areolar tissue.

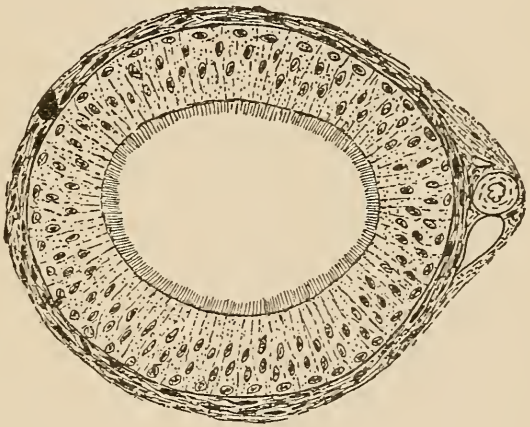


Fig. 212.—Cross section of epididymis.

The *vas deferens* begins at the lower margin of the globus minor and is a direct continuation of the

canal of the epididymis. It is a duct about twelve inches long, but when unraveled and extended it is eighteen to twenty inches in length. At first it is rather tortuous, but soon becomes straight and ascends along the inner border of the epididymis to pass directly to the external abdominal ring, taking a vertical course and forming a part of the spermatic cord. It then passes through the inguinal canal, and reaching the internal abdominal ring, turns quickly downward and inward to the side of the bladder upon which it descends, curving backward and downward to the neck of the bladder, where it enters the urethra through the prostate gland. In its abdominal course it lies external to the peritoneum, and along the bladder wall it arches between the latter and the ureter. Along this wall it becomes sacculated and near its terminus gives off a lateral, enlarged, and sacculated diverticulum, the *seminal vesicle.* The distal end beyond the opening of the seminal vesicle, is a narrow straight tube called the *ejaculatory duct.*

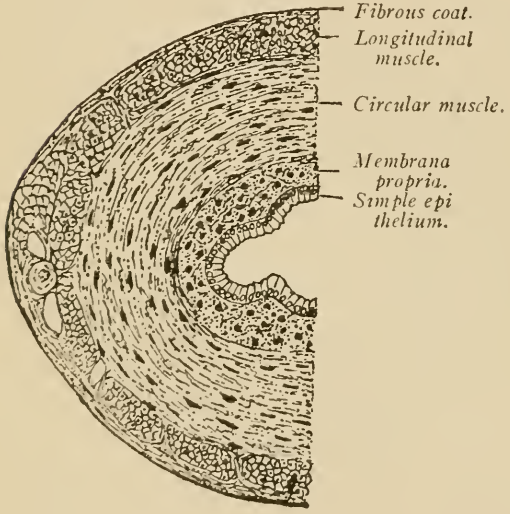


Fig. 213.—Cross section of vas deferens.

Structure.—The wall of the vas deferens has three

coats, an inner mucous, a middle muscular, and an outer fibrous. The *mucous membrane* generally presents two or three longitudinal folds and is lined with simple columnar epithelium. According to some investigators it may be ciliated in places and even resemble the transitional epithelium of the ureters. The membrana propria resembles that of other mucous membranes. No glands are present. The *muscular layer* is of the smooth variety. It consists of a strong inner circular and an outer longitudinal layer. Near the epididymis an extremely thin layer of longitudinal muscle fibers is present inside of the circular layer. The fibrous layer consists of loose areolar tissue, with which are associated blood and lymph vessels.

Paradidymis.—This consists of a set of branched tubules that leads off as blind diverticulæ from the canal of the epididymis or the vas deferens. There is one diverticulum or several of them. The length of these tubules when unraveled varies from two to twelve inches, and histologically they resemble the structure of the vasa efferentia. Morphologically the paradidymis is analogous to the paroöphoron found in the broad ligament of the ovary, the origin of both being associated with the development of the tubules of the mesonephros.

Hydatid of Morgagni.—There are two of these bodies. One of them, more constant than the other, lies usually between the globus major and the testicle and is called the *sessile hydatid*. It is a small cone-shaped body of epithelial cells and represents the peritoneal end of Müller's duct, the analogue of

the fimbriated end of the Fallopian tube in the female. The other is less constant and lies usually just external to the globus major and is called the *stalked hydatid*. It is an epithelial body and represents vestiges of the peritoneal end of the pronephric or Wolffian duct. The stalked hydatid is also present in the female, where it resembles a small cyst closely associated with one of the fimbriæ of the Fallopian tube.

The distance passed by the spermatozoa, before being eliminated by the urethra, is approximately twenty-four feet. The chief ducts and their lengths are: seminiferous tubules, each two feet long; epididymis, twenty feet; and vas deferens, two feet. The spermatozoa are themselves perfectly inactive in making this passage. During the copulation act they are discharged probably from the whole length of the vas deferens by peristaltic contraction of this duct, and not only from the seminal receptacle as formerly supposed. The supply of spermatozoa is extensive. If each testicle has eight hundred seminiferous tubules, each two feet long, then there are sixteen hundred feet of epithelial lining for each organ engaged in the production of spermatozoa. The semen consists of a fluid part, secreted mainly by accessory reproductive glands, and cell elements or spermatozoa that develop in the testes. In man there are about sixty thousand spermatozoa to each cubic millimeter of semen.

Vessels and Nerves.—The *spermatic artery* supplies the tubules of the testicles and the epididymis with blood directly from the abdominal aorta. It is a

long, slender artery that joins the spermatic cord as the latter passes through the inguinal canal. As the vessel approaches the testicle, it sends branches to the epididymis and then divides into other branches that ramify among the seminiferous tubules. The vas deferens receives a slender branch from one of the vesical arteries. This is called the *artery of the vas deferens*, and reaches as far as the testis, where it anastomoses with the spermatic artery.

The spermatic veins begin in the testis and epididymis and pass out at the posterior border of the organ, where they unite into large veins that form a plexus along the spermatic cord. Inside the abdomen this plexus unites to form a single trunk, the *spermatic vein*, which on the right side opens into the vena cava, and on the left side into the renal veins.

The **lymphatics** are very extensive and accompany the veins. They terminate in the lymphatic glands which encircle the large blood-vessels in front of the vertebral column.

The nerves are derived from the sympathetic system. There is a spermatic plexus that accompanies the spermatic artery, and some fibers from the hypogastric plexus that accompany the artery of the vas deferens.

THE PENIS.

The *penis* is a vascular organ composed principally of two *corpora cavernosa*, one *corpus spongiosum*, which encloses the urethra, and the *glans*, which is really the distal end of the corpus spongiosum.

The *integument* of the penis is very thin and loosely

attached. It is devoid of fat and hair and darker in color than the skin generally. Over the glans it is redoubled in a loose fold, the *prepuce* or *foreskin*. The inner layer of this fold is attached firmly to the base of the glans or cervix, and from there it becomes closely adherent to the glans as far as the orifice of the urethra, where it meets the mucous membrane of the latter. Over the glans it is red, thin, and moist, and beset with numerous large vesicular and

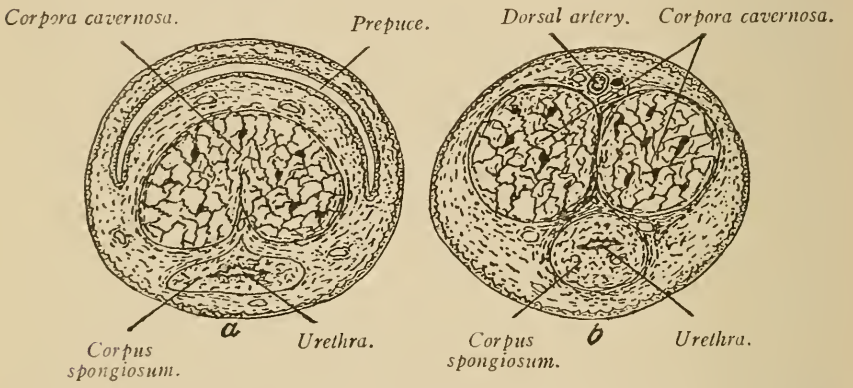


Fig. 214.—Cross section of penis: *a*, through the glans; *b*, through the body.

nerve papillæ, but devoid of glands, excepting around the cervix, where large sebaceous glands are numerous, called *glands of Tyson*, which secrete a white, waxy, odoriferous substance, *the smegma*.

The **corpora cavernosa** are two parallel cylindrical masses of erectile tissue that lie in the dorsum of the penis. They blend together in the anterior portion, and toward the root of the penis diverge to become firmly attached to the pubic and ischial rami. The anterior extremity of the corpora cavernosa is covered by the *glans penis*.

Structure of Corpora Cavernosa.—There is a median

fibrous septum between the two corpora cavernosa which becomes thin anteriorly and incompletely separates the two bodies. There is an external fibrous investment, very strong and elastic. This is composed mostly of longitudinal bundles of white fibers with interlacing elastic fibers. These fibers are intimately associated with the median septum and also with connective-tissue trabeculæ that ramify through the substance of the cavernous bodies. The substance of the latter is called erectile tissue and is of a spongy nature. The trabeculæ anastomose and interlace freely to form a multitude of interstices or cavernous spaces. These are filled with venous blood, and are really a complex system of veins lined by a layer of flattened epithelium as in other veins. In the anterior portion of the penis the venous labyrinth of one corpus cavernosum intercommunicates with that of the other through the incomplete septum. In the erectile condition the corpora cavernosa are distended with blood which is carried away by two sets of veins, the one set joining the prostatic plexus and the pudendal veins, and the other draining into the dorsal vein of the penis. The arterial blood is supplied mainly by branches of the pudic arteries, but the dorsal artery of the penis sends a few branches through the fibrous sheath, particularly in the forepart of the organ. The arteries ramify in the trabeculæ and terminate in minute capillary branches that open into intertrabecular spaces. Some of the smaller arteries project into the spaces, forming peculiarly twisted or looped vessels called *helicine arteries*.

The **corpus spongiosum** is also composed of erectile tissue, but is a single cylindrical body that lies below and between the corpora cavernosa. Its posterior extremity is much enlarged and rounded, and is called the *bulb*. This lies in the ventral portion of the root of the penis just in front of the triangular ligament. Anteriorly the corpus spongiosum forms the *glans penis*, which caps the corpora cavernosa. The border of the glans is rounded and projecting and is called the *corona glandis*, behind which is a constriction of the penis, the *cervix*. In the whole of its extent the corpus spongiosum encloses the urethra.

Structure of Corpus Spongiosum.—This resembles the erectile tissue of the corpora cavernosa, and like the latter is distended with blood during erection, but is less rigid. The venous labyrinth is a finer meshwork and the trabeculæ and fibrous tunic is much thinner. In the glans the meshes are particularly small and uniform. Plain muscle fibers enclose the urethra and also form a part of the external coat.

Urethra in the Male.—The male urethra extends from the bladder to the end of the penis, in length about eight and one-half inches. Its walls are in apposition, excepting during the passage of urine or semen. The urethral cleft in the glans is vertical; in the body of the penis it is transverse; and through the prostatic portion near the bladder it is crescentic. It is lined by a mucous membrane, external to which is a double layer of smooth muscle fibers, the inner fibers disposed longitudinally and the outer circular. For descriptive purposes the urethra is divided into

a *prostatic portion*, a *membranous portion*, and a *spongy* or *penile portion*.

1. The *prostatic portion* is about one and one-fourth inches in length and passes through the prostate gland. This is the widest portion of the urethra and passes vertically from the neck of the bladder to the triangular ligament of the perineum. In cross section the canal is crescentic with its convexity turned forward. The lining membrane presents longitudinal folds, and along the posterior wall is a prominent median ridge which gives rise to the crescentic form of the urethra when seen in sections. This ridge is called the *crista*, or *verumontanum*. The longitudinal groove on each side of the crista is called the *prostatic sinus*, which is pierced by numerous orifices of the prostate gland. In the middle of the crista is the orifice of a blind recess, and at the lateral margins of this are the slit-like openings of the seminal or ejaculatory ducts. The median or blind recess is a cul-de-sac which passes upward and backward for a distance of one-fourth to one-half inch, and is called the *sinus pocularis* or *masculine uterus*. It represents embryologically the fused ends of Müller's duct, and is therefore morphologically equivalent to the female uterus. The epithelium of this part of the urethra resembles that of the bladder and is of the transitional variety. In the sinus pocularis it is said by some to be simple ciliated like that of the uterus.

2. The *membranous portion* is about three-fourths inch in length and lies between the two layers of the triangular ligament. It is the narrowest part of the

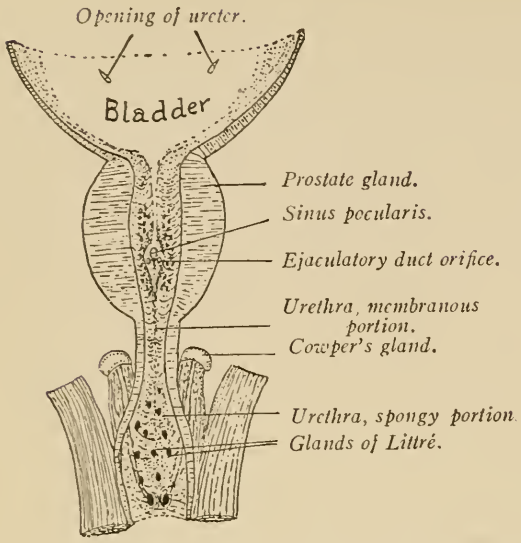


Fig. 215.—Diagram of male bladder and urethra, front view.

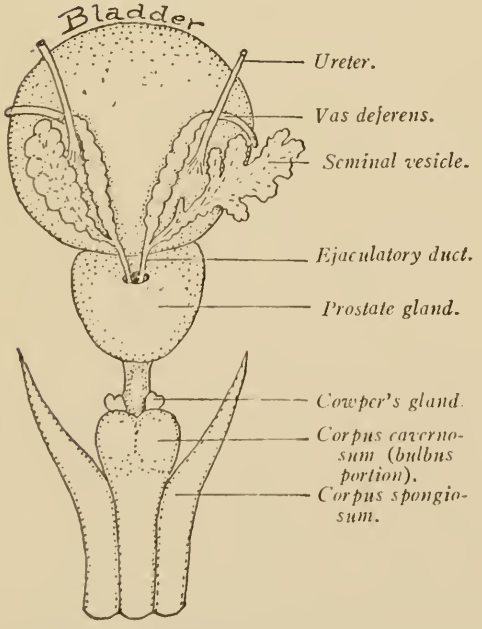


Fig. 216.—Diagram of male bladder and urethra, posterior view.

urethra, not more than one-fifth inch in diameter, and curves so as to be directed downward and slightly forward beneath the pubic arch. The epithelium in this part varies. Portions of it resemble that of the bladder, but more often it presents the appearance of pseudo-stratified with two or three layers of nuclei.

3. The *spongy portion* is by far the longest and most variable in length and direction. Its length is about six inches, and its entire course is in the corpus spongiosum. The epithelial lining near the meatus is strati-

fied squamous, and directly continuous with the skin. The rest of this portion is lined by columnar pseudo-stratified epithelium with two or more rows of nuclei.

The whole length of the urethra, excepting its distal end, is beset with small racemose mucous glands called *glands of Littré*. These vary much in size, some of them being sacculated. Most of them open in the floor of the urethra, their ducts passing obliquely forward through the lining membrane. In urethral infections these glands become involved, as a rule, which increases the difficulty of eliminating the disease.

The Urethra in the Female.—The female urethra is about one and one-half inches in length, and corresponds to the male urethra between the bladder and the opening of the ejaculatory ducts. It is directed downward and forward parallel to the anterior wall of the vagina, to which it is attached. The transverse diameter of the closed tube is about one-fourth inch, but it is capable of great distention, sufficient to admit the index finger. The external orifice, or meatus, is a vertical slit with prominent margins, on which may be seen the orifices of two small glands, called *Skene's glands*. The latter are subject to infection in urethral disturbances and often give rise to severe irritations.

THE PROSTATE GLAND.

The *prostate gland* is a muscular as well as glandular organ that surrounds the prostatic portion of the male urethra. It atrophies in the adult after cas-

tration, and remains undeveloped if the testicles are removed in infancy, which supports the view that it is an accessory organ of generation. Its size varies considerably, but its average transverse or longest diameter is one and one-half inches, its antero-posterior diameter about three-fourths inch, and its vertical diameter one and one-fourth inches. Since the urethra, and also the ejaculatory ducts, pass through the organ, the gland on this account may be divided into three lobes. The wedge-shaped portion that lies between these ducts and the cervix of the bladder is called the *middle*

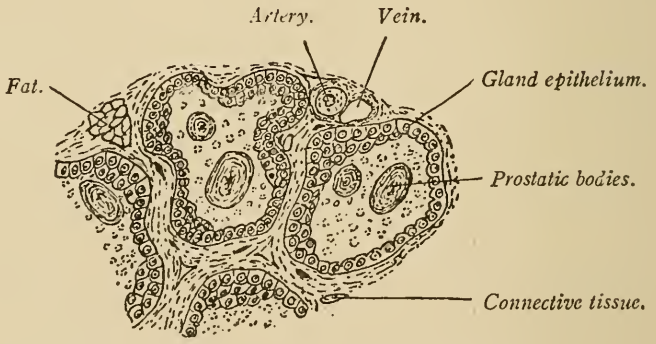


Fig. 217.—Section from the prostate gland

lobe, and the rest of the gland is spoken of as the *lateral lobes*. It is the latter that often hypertrophy in old age and are removed in prostatectomy. The gland lies in close apposition to the rectum, and with the finger in the latter it can readily be palpated.

The prostate is a compound tubulo-alveolar gland whose ducts open into the prostate portion of the urethra. Smooth muscle fibers not only surround the

organ, but interlace radially toward its center, forming a network in whose meshes the glandular parts are located. Areolar tissue and blood-vessels accompany the muscle tissue. The alveoli of the glands are lined by simple columnar epithelium, which sometimes show two rows of nuclei. These alveoli contain a serous acid coagulum and usually oval laminated concretions called *prostatic bodies*. The latter are more numerous in old men. The numerous excretory ducts unite to form twelve to fifteen collecting tubes which open into the urethra, most of them into the *prostatic sinus*. These ducts are lined by simple columnar epithelium, except near their terminations where it is transitional. The organ dorsal or in front of the urethra is mostly smooth muscle tissue.

In old people the prostate gland frequently hypertrophies and produces urethral stricture with retention of urine. Prostatectomy or the removal of the lateral lobes, usually corrects this defect, but is a serious operation on account of the commonly feeble condition of these patients. Vasectomy, a much simpler operation, sometimes gives satisfactory results, but is not to be relied upon.

Cowper's glands are a pair of small oval bodies about the size of a pea, situated in the space between the triangular ligaments and in close proximity to the membranous portion of the urethra. They are compound tubulo-alveolar mucous glands lined by simple cubical epithelium. Their excretory ducts, one for each gland, are one and one-half inches long

and run forward near each other to open into the floor of the bulbous portion of the male urethra.

In the female the analogue of these bodies is called the *glands of Bartholin*. They open into and lie in close apposition to the female urethra. They may be palpated in the lateral walls of the vestibule of the vagina.

CHAPTER IX.

REPRODUCTIVE ORGANS IN THE FEMALE.

Under this head will be described the ovaries, Fallopian tubes, uterus, vagina, and mammary gland.

THE OVARIES.

The ovaries are two dehiscent glandular organs that develop from the mesoderm in close apposition to the mesonephros. Each ovary measures about one and one-half inches in length, three-fourths inch in breadth, and nearly one-half inch in thickness. In early fetal life the ovaries lie close to the kidneys, but later they pass down into the pelvis where they lie in close proximity to the iliac fossa. The exact position varies considerably, but in the majority of cases they will be found placed against the side wall of the pelvis with their long axis parallel to that of the body. Each ovary is held in position by a *suspensory ligament*, which is a peritoneal fold that passes downward from the brim of the pelvis and contains the ovarian vessels and nerves, and also by the *ovarian ligament*, which passes to the uterus and is really a reduplication of the broad ligament. The Fallopian tube partly encircles the ovary and also contributes to its support.

Capsule of the Ovary.—The external surface of the

ovary is of a pale color and in early life is smooth and even, but in later life it becomes rough and marked by pits and scars. This is caused by the rupture of Graafian follicles and the expulsion of ova. It is covered by an epithelium which is continuous with that of the peritoneum, but differs from the latter

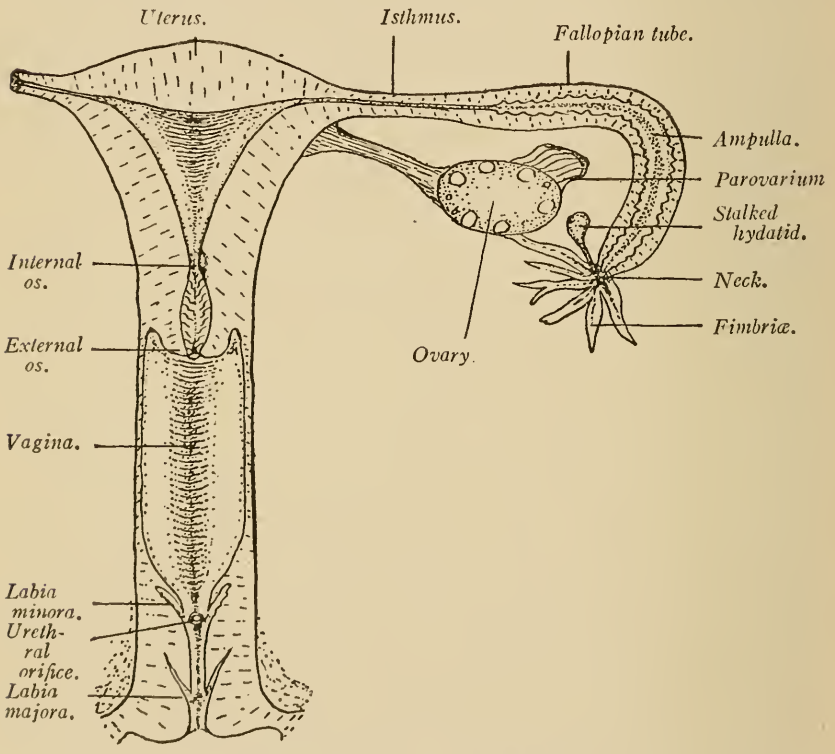


Fig. 218.—Diagram of female genitalia.

in being lined by cubical cells instead of the simple pavement variety. This ovarian epithelium is the *germinal epithelium* of embryos, from which the ova and the other epithelial cells of each Graafian follicle are derived. The germinal epithelium rests upon a rather dense investment of fibrous tissue, analo-

gous to a like structure in the testicle, and is therefore called the *tunica albuginea*. This is not a distinct tunic but rather a condensed part of the ovarian matrix. It is not well defined, and is difficult to demonstrate in sections.

The medulla is practically the core of the ovary and consists of a fibro-muscular matrix well supplied

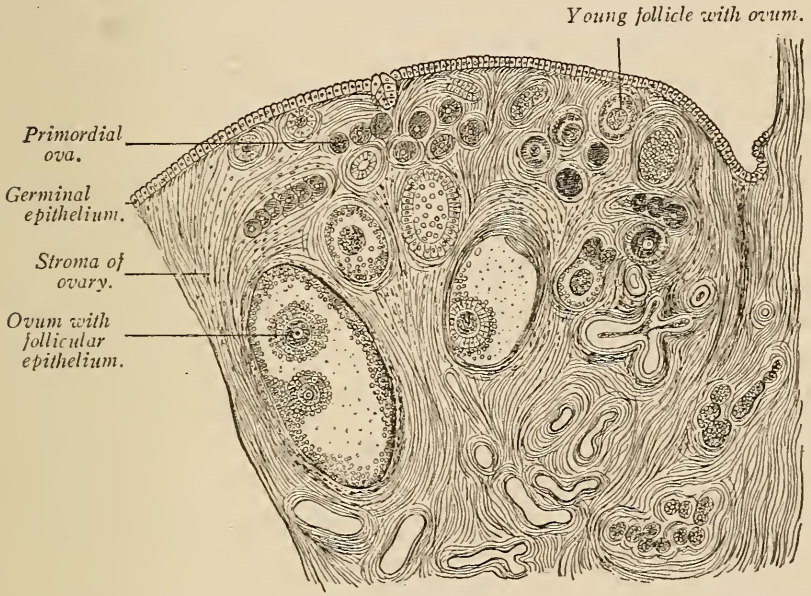


Fig. 219.—Section from ovary of adult dog. At the right the stellate figure represents a collapsed follicle with its contents. Below and at the right are seen the tubules of the parovarium (copied from Waldeyer).

with blood- and lymph-vessels. In this substance may be found connective-tissue cells, connective-tissue fibers and a limited supply of smooth muscle fibers.

The Cortex.—Between the medulla and the capsule is the cortex. It is a broad zone, not well defined, in which are found the same elements as in the

medulla, and in addition Graafian follicles in different stages of development, and in older ovaries also *corpora lutea*.

Young Graafian Follicles.—Early in embryonic life, when the ovary is clothed with the germinal epithelium which later becomes the epithelium of the capsule, epithelial buds or strings of epithelial cells push their way into the ovarian cortex. These buds soon lose their connection with the germinal epithelium and form little groups or nests of cells known as young Graafian follicles. In each follicle one cell takes a central position and is the *egg cell* or *ovum*, destined, under proper conditions, to develop into a new being. The ovum increases rapidly in size, receiving protection and possibly nourishment from the investing cells. The reproductive cells, both ova and spermatozoa, can thus be traced directly from the germinal epithelium, which is of mesodermic origin and closely related to the pavement epithelium of the peritoneum.

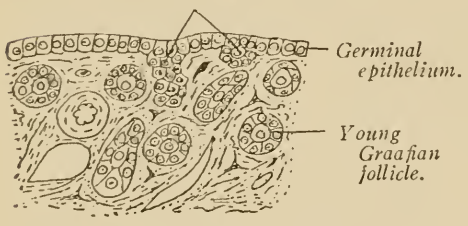


Fig. 220.—Section from ovary of young dog.

The Graafian follicles occupy the cortical layer of the ovary. They are all formed during embryonic life, and whatever influence environment has upon the offspring, that influence leaves its impression not upon the origin of the reproductive cells, but upon their later development. At time of birth it is esti-

mated that there are thirty-five thousand eggs or ova to each ovary. Only a small number of these ripen and become discharged as mature eggs. The extrusion of these eggs from the ovary is known as *ovulation*, and in woman is supposed to occur during the menstruation period, one from each ovary. Menstruation in a normal woman extends generally over a period of thirty-two years, between the ages of thirteen and forty-five. If thirteen eggs ovulate yearly from each ovary, there will be a possible total

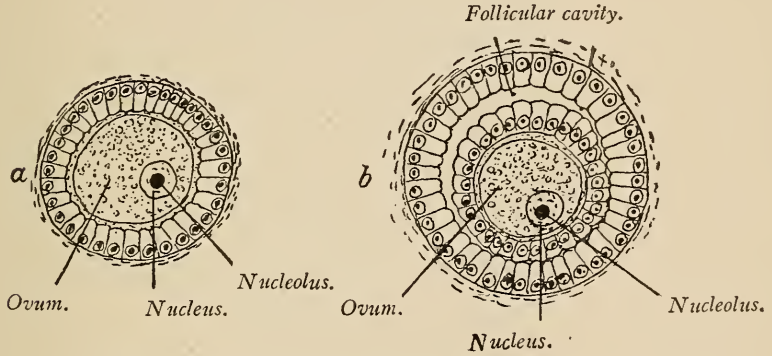


Fig. 221.—Young Graafian follicles: *a*, follicle with one layer of epithelial cells; *b*, follicle with two layers of epithelial cells.

of eight hundred and thirty-two that may ripen during the life of a woman, allowing no interruption for pregnancies. After the menopause, ovulation is supposed to cease.

The Ripe Graafian Follicle.—It has already been stated that only a small number of the young ova ripen and ovulate. These mature in the following manner: The ovum of such follicles occupies a central position where it accumulates food and grows into a large spherical cell. The investing epithelium

forms at first a single layer of cells. These remain small and multiply rapidly, forming two layers of cells between which, at one side of the follicle, a cavity appears. As the follicle grows larger this cavity, which is eccentric in position, becomes filled with a fluid called the *follicular fluid*. The ovum remains attached to the side of the follicle and becomes surrounded by several layers of cells called the *discus proligerus*. The outer layer also multi-

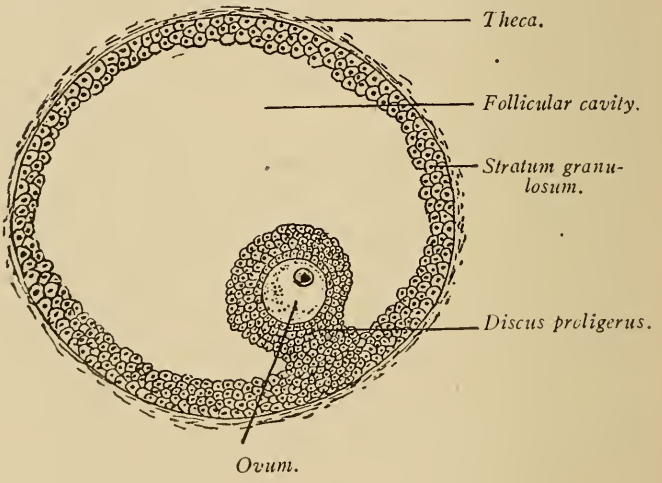


Fig. 222.—Ripe Graafian follicle.

plies, forming eight to twelve layers of cells and is then called the *stratum granulosum*, to which the discus proligerus is attached. External to the stratum granulosum a connective-tissue envelope forms, called a *theca*. This theca develops from the ovarian stroma and consists of two layers, an external, the *theca fibrosa*, and an internal, the *theca vasculosa*, the latter being supplied with a fine plexus of lymph- and blood-vessels. The mature

Graafian follicle is thus a sphere that measures from one-twentieth to one-sixth of an inch in diameter, and lies immediately beneath the surface epithelium of the ovary.

The manner in which such follicles rupture has been variously explained. One rational theory is

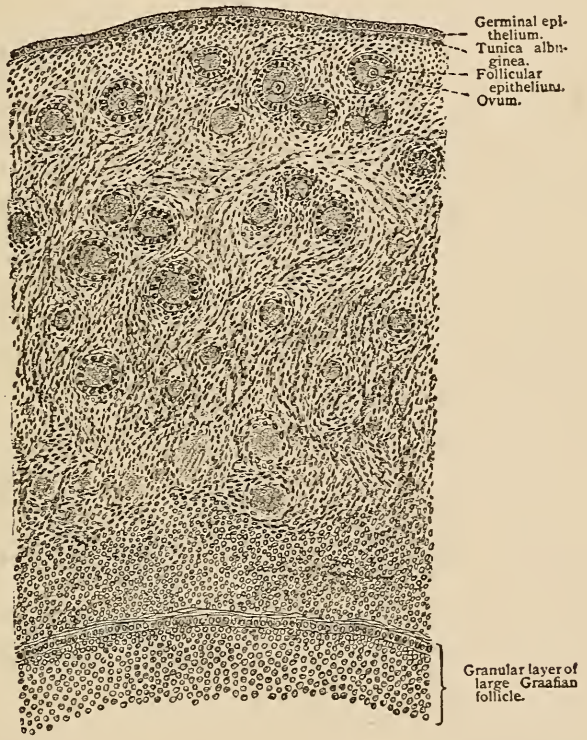


Fig. 223.—From ovary of young girl (Böhm and Davidoff).

that the pressure of the accumulated follicular liquid obliterates the blood-vessels in the theca vasculosa next to the ovarian epithelium. This establishes a point of least resistance at this place, the follicle ruptures, and the follicular fluid with the ovum is discharged upon the surface of the ovary, the

stratum granulosum and most of the discus proligerus remaining behind in the ovary.

The Ovum.—The ovum has already been mentioned as a large spherical cell with a large accumulation of food material. It measures 0.2 mm. in diameter and is barely visible to the naked eye. When examined under the microscope, even before the rupture of its follicle, it is found encircled by a clear substance called the *zona pellucida*, which upon a closer examination may be found to contain transverse striations, hence it has also been called *zona radiata*. It is not uncommon for a few of the epithelial cells of the discus proligerus to remain attached to this layer, if so they are called the *corona radiata*. The zona pellucida is a secretion from the adjoining cells, and one theory of the transverse striations is that they are produced by minute cellular processes from the cells that form the corona radiata; that is, the first row of epithelial cells investing the ovum. It is affirmed by some that these processes are in direct communication with the substance of the ovum and are the means by which elaborated food material is contributed to the latter. The zona pellucida no doubt serves to strengthen the delicate ovum after its expulsion from the ovary. The transverse striæ in this membrane may serve a further purpose as primitive channels for the entrance

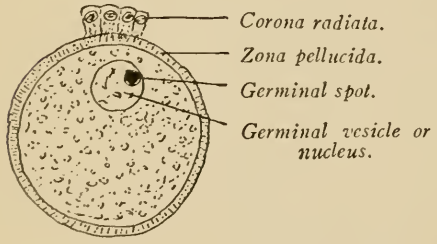


Fig. 224.—The ovum.

of spermatozoa, only one of which penetrates the substance of the ovum.

The substance of the ovum is known as the *vitellus*. It is a soft semifluid substance composed of cytoplasm in which is deposited a liberal supply of food material called *deutoplasm*. The nucleus of the

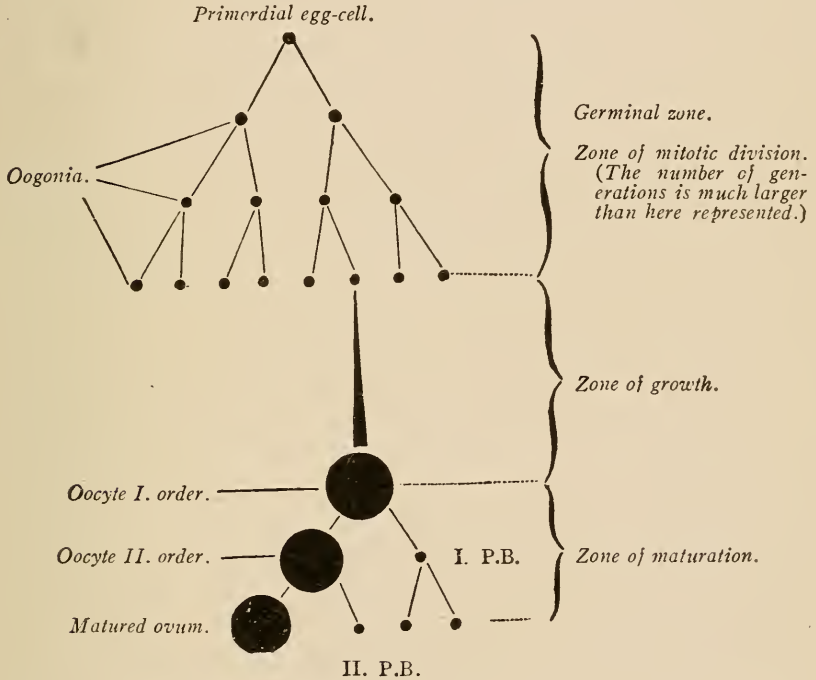


Fig. 225.—Scheme of the development and maturation of an ascaris ovum (after Boveri): P. B., Polar bodies. (From "Ergebn. d. Anat. u. Entw.," Bd. I.)

ovum is called the *germinal vesicle*, which is placed to one side of the cell. The nucleus is unusually large, about 0.05 mm. in diameter, and has all the characteristics of an ordinary cell nucleus. This was first described by Purkinje in the ovum of birds in 1835. There is a well-defined nuclear membrane

which encloses a clear nuclear substance in which there is a limited amount of chromatin, and the nucleus, therefore, does not stain heavily. The nucleolus, on the other hand, is very prominent and is called the *germinal spot.* Not infrequently two nucleoli may be found. There is some doubt whether a cell membrane to the ovum is present before fer-

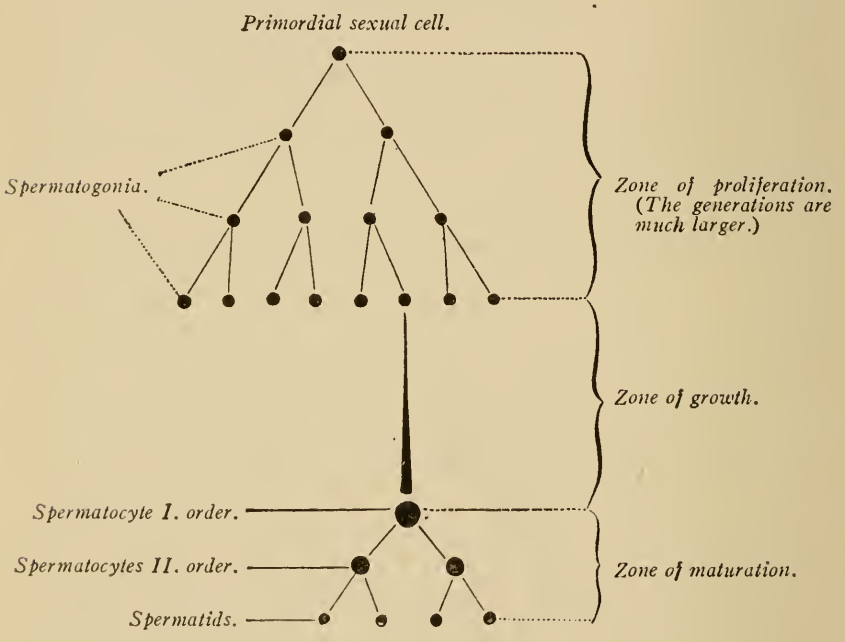


Fig. 226.—Schematic diagram of spermatogenesis as it occurs in ascaris (after Boveri). ("Ergebn. d. Anat. u. Entw.," Bd. 1.)

tilization. After fertilization such a membrane appears and is called the *vitelline membrane.* As a rule each Graafian follicle contains one ovum; in rare cases follicles are found with two and even with three ova.

When a Graafian follicle ruptures and an ovum is

expelled, a great activity is at once manifest in the ovum, whether it is fertilized or not. The nucleus, which is near the margin of the ovum, divides in a few hours, extruding what is termed the *first polar body*. This is normal cell division, or mitosis. A second division quickly follows, resulting in a *second polar body*. Meanwhile the first polar body may also divide. This second division results in a reduction of one-half the number of chromosomes, and the nucleus thus reduced is called the female pronucleus, which is now ready to unite with the male pronucleus of the spermatozoön and complete the process of fertilization. The phenomenon manifest in the extrusion of the polar bodies is known as *maturation of the ovum*, and seems to be an attempt on the part of the ovum to develop into a new individual without the process of fertilization; that is, *parthenogenetically*. If the ovum is not fertilized, it shows no further activity and is lost. If the ovum is fertilized it continues to divide regularly and in a short time develops into the embryo.

The developmental history of ova is full of interest. They are very numerous and develop so very early in embryonic life. During childhood they grow large and accumulate a liberal storage of food, while the sister epithelial cells that form the Graafian follicle remain small and multiply rapidly to form the ripe follicle. This latent condition extends over a period of fifteen to forty years. When the ripe follicle finally ruptures and the ovum is eliminated, a rapid segmentation quickly follows resulting in the extrusion of the polar bodies. This is followed by a

second passive period, unless fertilization takes place, when the ovum rapidly develops into a new being. By far the large majority of the ova remain undeveloped in the ovarian cortex, where they seem to pass merely a passive existence. We have no explanation of these phenomena beyond attributing them to heredity, the nature of which is still highly speculative.

The Corpora Lutea.—A corpus luteum is the modified Graafian follicle after its rupture and discharge

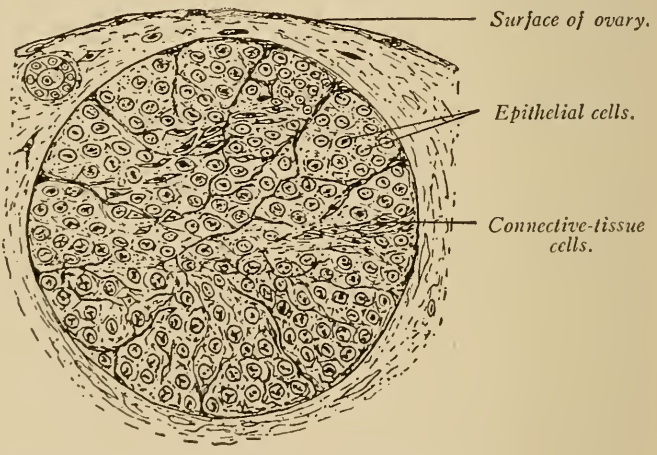


Fig. 227.—Section of corpus luteum.

of the ovum. This follicle remains permanently in the cortex of the ovary as a scar. When the rupture takes place the follicular cavity fills up with an exudate and an infusion of blood from the ruptured blood-vessels. This coagulum is quickly invaded by white blood-corpuscles, connective-tissue cells from the theca, and epithelial cells from the stratum granulosum. The corpus luteum thus ultimately shows a uniform distribution of epithelial

cells and connective-tissue cells. If the ovum becomes fertilized and pregnancy follows, the corpus luteum continues to grow until it becomes many times larger than the original Graafian follicle, causing a rounded elevation at that point on the surface of the ovary. This kind is called a *true corpus luteum*. On the other hand, if the ovum is not fertilized the corpus luteum shrinks and becomes smaller than the original follicle. This kind is called a *false corpus luteum*. The corpus luteum is at first well defined by the investing follicular theca, but after a time its limits are less distinct, so that as age advances the ovarian stroma becomes gradually pervaded with cells like those of the corpora lutea.

THE FALLOPIAN TUBES.

The Fallopian tubes are two ducts for the passage of ova from the ovary to the uterus. They differ from the ducts of other glandular organs in being detached from the organs whose secretions they convey. They are from four to five inches long and pass almost horizontally outwards from the fundus of the uterus. When they reach the ovary they ascend along the pelvic floor and nearly encircle each organ, passing up the external and down the internal or mesial margins. Each tube is enclosed in the free margin of the broad ligament, which is a peritoneal fold that also contains the round ligament of the uterus, the ovary, parovarium, and numerous blood- and lymph-vessels.

For descriptive purposes each duct is divided into an *isthmus*, an *ampulla*, a *neck*, and a *fimbriated ex-*

tremity. The *isthmus* is smooth and round, about one inch in length, and opens into the fundus of the uterus by a small orifice that will barely admit an ordinary bristle. It is a straight and narrow part of the duct, about 2 to 3 mm. in diameter. The *ampulla* encircles the ovary and is at least twice the size of the isthmus. It is also less firm to the touch,

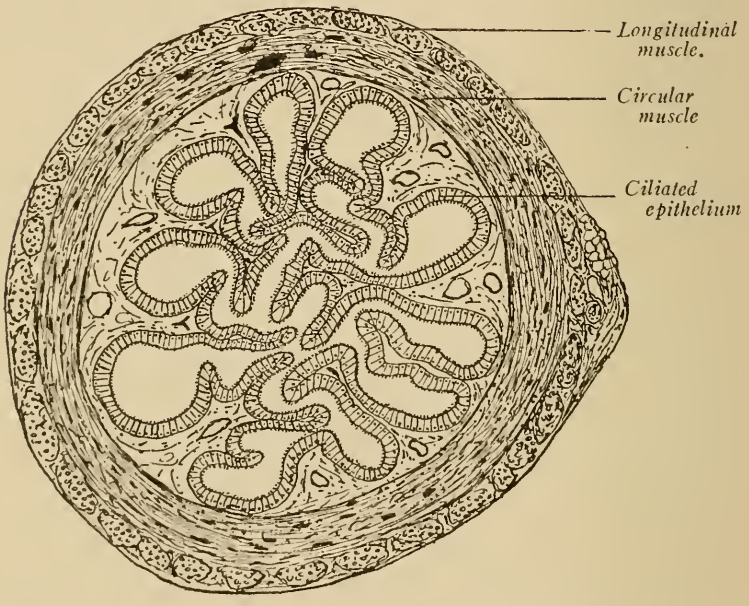


Fig. 228.—Cross section of ampulla of Fallopian tube.

being flabby while the isthmus is cord-like. The *neck* is an annular constriction between the ampulla and *fimbriated extremity*, the latter being a funnel-shaped expansion of the ovarian end of the tube, which terminates in a number of irregular processes called *fimbriæ*. The fimbriæ vary considerably in size and number. Many of them are branched, and

one is particularly long and attached to the upper end of the ovary.

Structure.—The Fallopian duct is a muscular tube lined the whole length by a mucous membrane clothed with simple ciliated columnar epithelium. This mucous membrane is thrown up into longitudinal folds that are very broad and numerous in the wide portions of the tube and in the narrow portions less conspicuous. It is continuous on the one hand

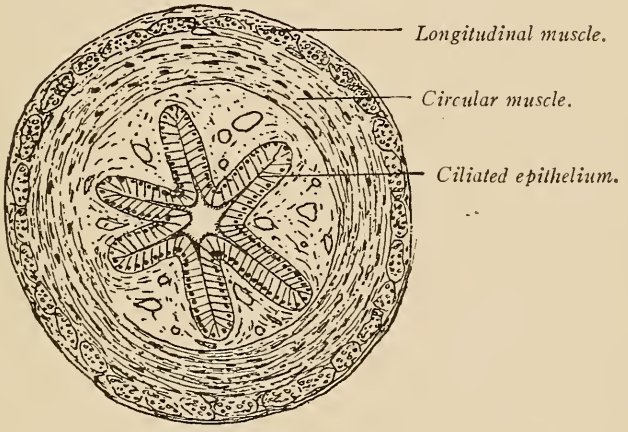


Fig. 229.—Cross section of isthmus of Fallopian tube.

with the mucous membrane of the uterus, and at the other end of the tube with the serous lining of the peritoneum, being one example of a direct continuity of a mucous and a serous membrane. Glands, so numerous in the mucous membrane of the uterus, are absent in the Fallopian tube.

The mucosa rests upon a thin vascular submucosa composed of areolar tissue. External to the submucosa there is a muscular coat consisting of a thick inner circular layer and a thin outer longitudinal

layer of smooth muscle fibers. Externally the tube is practically enclosed by the peritoneum, forming a serous covering.

Embryologically, each Fallopian tube represents a Müllerian duct, which is derived from the mesoderm. In the male the Wolffian duct develops into the vas deferens. This duct, which is rudimentary in the female, is called Gärtner's duct, and lies parallel to the Fallopian tube, between the latter and the round ligament. The round ligament extends from the uterus to the internal abdominal ring in nearly the same position as the vas deferens does in man.

Fertilization, as a rule, takes place in the upper part of the Fallopian tube. In cases of tubal pregnancy the ovum does not reach the uterus but finds lodgment in the tube. The much-folded mucous membrane allows considerable distention, but ultimately the rapidly growing embryo ruptures the tube, with serious complications resulting from internal hemorrhage. Usually the ova pass down the tube on the corresponding side, but it is possible for the ova from one ovary to pass down the tube of the opposite side. Experimentally, the right ovary and the left tube may be removed in the dog and the animal still become pregnant.

The ovaries have a marked influence on the development and mentality of a woman and their removal, prior to the menopause, is followed by deleterious results, much the same as the removal of the testes in the male. While extracts from certain organs, such as the thyroid gland and the suprarenal bodies, have specific medicinal properties, extracts from the

ovaries give no satisfactory results. Its potency is manifest only by the living organ in the performance of its normal function. The ovary or fragments of it will readily grow in other parts of the body, and has been successfully grafted from one animal to another.

The Parovarium, or Epoöphoron.—The organ bearing this name lies in the broad ligament lateral to the ovary and between the latter and the tube. It consists of a number of closed epithelial tubules which can usually be seen by holding this part of the ligament up against the light. Embryologically they represent the upper portions of the Wolffian duct and some of the attached tubules of the mesonephros, and correspond to the vasa efferentia in the male.

The paroöphoron represents vestiges of tubules similar to the parovarium, situated in the broad ligament below the ovary. They correspond to the paradidymis in the male.

Being lined by epithelial cells, either of these organs may develop into parovarian or paroöphoron cysts, the former being more common.

THE UTERUS.

The uterus, or womb, is a hollow muscular organ, with thick walls, placed in the pelvic cavity between the bladder and rectum. In case of pregnancy it receives and nourishes the ovum and later expels the fetus at the end of pregnancy. During gestation, and also periodically during menstruation, it is subject to marked physiological and structural changes.

It is therefore an organ in which great activity is manifest during the greater part of adult life.

The fully developed virgin uterus is a pear-shaped organ, flattened from before backward, free above,

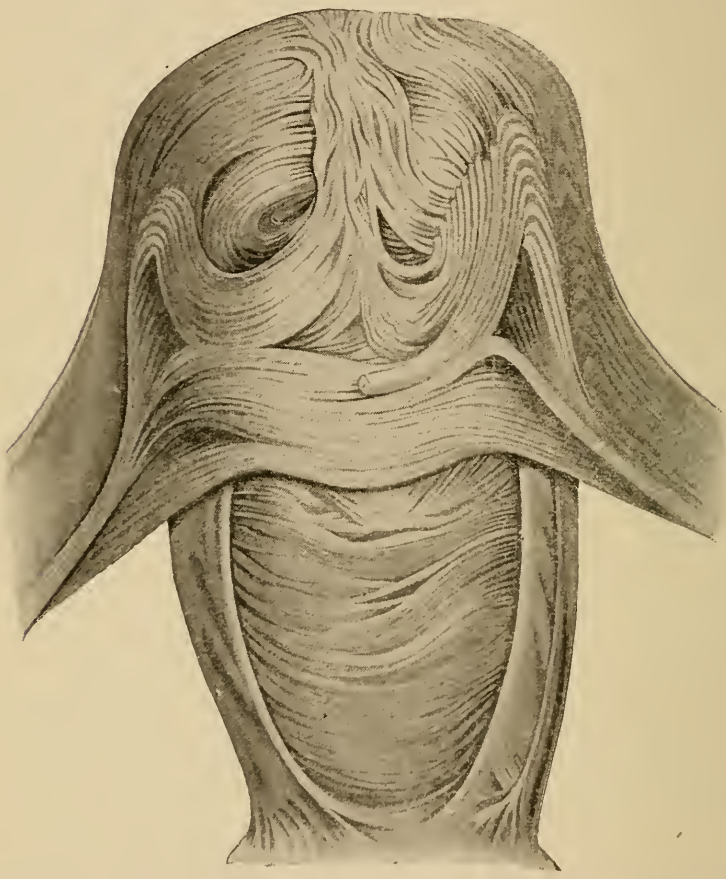


Fig. 230.—Arrangement of uterine muscle, as seen from in front after removal of serous coat (Hélie).

and connected below with the vagina, into which its lower extremity projects. Its average dimensions are, three inches in length, two inches in breadth at its upper and widest part, and one inch in thickness.

For descriptive purposes it is divided into *fundus*, *body*, and *neck*, or *cervix*.

The *fundus* is the broad convex upper end that lies above the attachment of the Fallopian tubes. It is chiefly this part that expands in case of pregnancy. The *body* is the part between the fundus and neck. This part tapers downward with convex sides. The

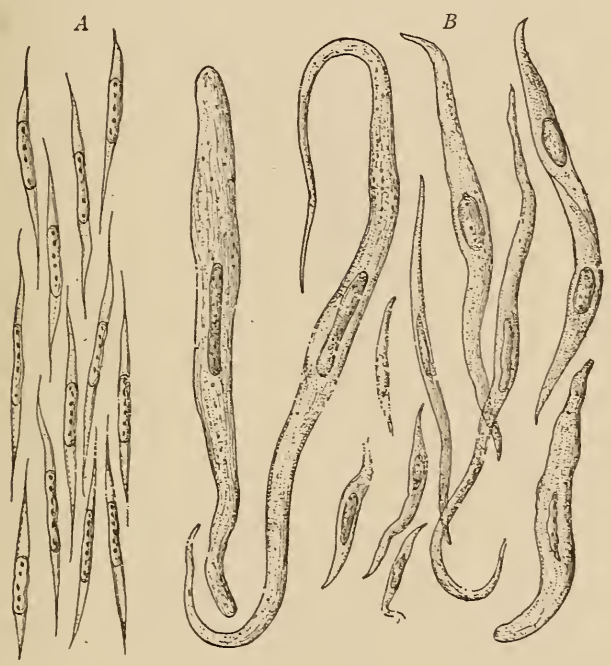


Fig. 231.—A, Isolated muscle-elements of the non-pregnant uterus; B, cells from the organ shortly after delivery (Sappey).

neck, or *cervix*, is about one inch long, cylindrical, and projects into the anterior part of the upper end of the vagina. The projecting portion is called the *vaginal part*, and has a transverse oval aperture, called the *os uteri*, which communicates with the cavity of the uterus. The latter is a triangular

cavity, so flattened that the anterior and posterior uterine walls touch each other. The base of the cavity is in the fundus and is convex downwards. The two Fallopian tubes open into the upper angles each by a small aperture that will barely admit a bristle. The cavity tapers gradually toward the cervix, where it becomes constricted to form the internal os. The peritoneum covers the fundus and

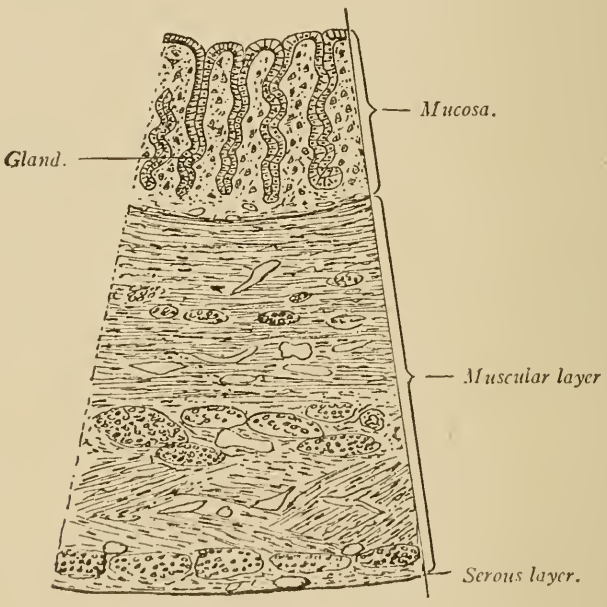


Fig. 232.—Cross section of wall of uterus.

body of the uterus, and posteriorly extends downward to clothe the upper posterior wall of the vagina. It is then reflected back over the rectum, forming a a sac called the pouch of Douglas. This makes it possible to open the peritoneal cavity by a puncture through the upper posterior vaginal wall, an operation which establishes free drainage to the female pelvis.

Anteriorly the peritoneum does not cover the whole uterus, but at the junction of the body with the neck, it is reflected back over the bladder wall forming the utero-vesical pouch.

Structure.—The histology of the uterus resembles that of the Fallopian tubes, and the layer of the one is continuous with that of the other. Embryologically, these two structures, and also the vagina, develop from the Müllerian ducts, the uterus and

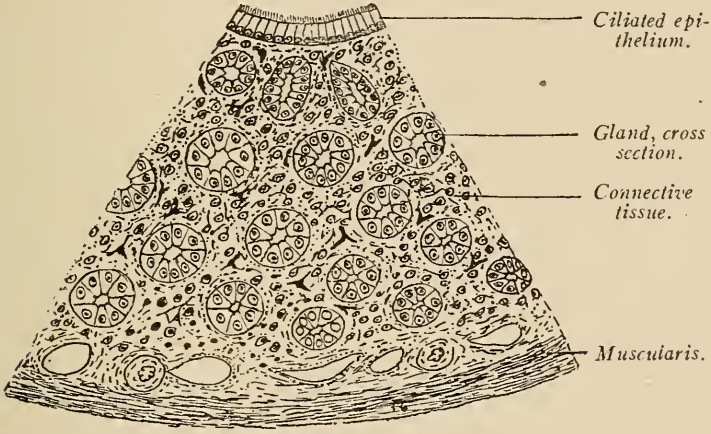


Fig. 233.—Diagonal section of the uterine mucosa.

vagina representing the fused lower ends of Müller's ducts. The whole uterus, including the epithelial lining, is therefore of mesodermic origin. The uterine wall is composed of a mucosa, muscular, and serous layer. The Fallopian tube has a submucosa which is absent in the uterus.

The *mucosa*, or *endometrium*, is the inner layer and is lined by simple columnar ciliated epithelium, which at the external os changes to the stratified variety of the vagina. It has a rich supply of

branched tubular mucous glands which, in the cervix, are very large and have a tendency to become sacculated. These glands extend radially as far as the muscularis, and some of them may even penetrate a short distance into the muscle coat. The gland ducts are lined by ciliated epithelium, while in the deeper portions cilia are absent and the epithelium becomes simple cubical, resembling a glandular type. Most of these glands take a tortuous or spiral course, and are separated from each other by an interstitial tissue composed of connective-tissue cells. These cells are of the embryonic type, rich in chromatin and therefore stain heavily with nuclear dyes. The relative amount of interstitial and glandular tissue in a normal uterine mucosa should be approximately equal parts. The connective tissue predominates in interstitial endometritis, and the glandular tissue in adenitis. The whole uterine mucosa is unusually thick and very vascular. In a mature woman it is normally subject to marked periodic changes resulting from menstrual conditions, which reach a high degree of complexity in case of pregnancy. The action of the cilia tend to produce a downward movement of the uterine secretions and, therefore, opposite to the upward movement of spermatozoa.

The Muscular Layer.—The muscularis is an unusually thick layer of smooth muscle cells which in the non-pregnant uterus measure forty to sixty microns, while at the end of pregnancy the cells measure four hundred to six hundred microns in length. These muscle cells are arranged in bundles with a considerable amount of connective-tissue fibers and

cells interlacing them, imparting strength and elasticity to the uterine wall. There has been considerable discussion as to the exact disposition of the different layers of this musculature which, in a general way, may be divided into three strata: (1) an inner layer of longitudinal fibers, by some called the muscularis mucosa; (2) a middle circular layer, and (3) an outer thin layer of fibers that run diagonally or somewhat irregularly. The inner layer is much the thickest; none, however, is sharply defined.

The *serous coat* is the peritoneal lining which consists of connective-tissue elements and an investment of simple pavement epithelium.

Vessels and Nerves.—The arteries that supply the uterus are arranged in two pairs,—the uterine and ovarian. The uterine artery is a branch of the anterior division of the internal iliac. It reaches the upper portion of the vagina, and then ascends in a very tortuous manner along the lateral border of the uterus to the fundus, where it divides into two branches, one of which anastomoses with the ovarian artery and the other supplies the Fallopian tube. From the ascending portion many side branches are given off which penetrate the uterine wall and ramify in the muscle tissue and the mucosa. These branches are very tortuous so that the uterus can expand in pregnancy without breaking the vessels.

The *veins* are very large and have no valves. They form large sinuses mostly along the lateral walls, from which the blood is collected into two trunks: (1) the uterine vein accompanies the uter-

ine artery and empties into the internal iliac vein; (2) vessels communicate with the *ovarian* or *pampiniform* plexus which drains through the ovarian veins.

The *lymphatics* begin in the interstitial substance of the mucosa, and uniting with lymphatics from the muscularis, emerge to form a rich plexus just beneath the serous covering. This plexus drains along two channels: (1) by lymphatic vessels that accompany the uterine veins; (2) vessels that accompany the ovarian veins. The blood and lymph drainage is therefore in two directions. That of the fundus is toward the ovary, and that of the body and cervix is in the opposite direction along the uterine vessels. This is of clinical importance in the spread of infections.

The *nerves* are non-medullated fibers from the *inferior hypogastric plexus*, and medullated from the *third* and *fourth sacral*. The non-medullated supply the muscle while the medullated fibers have been traced to the mucosa, where they form a plexus from which fibers pass to the surface epithelial cells. Another set arborize about the mucous gland cells. Sympathetic-nerve ganglia are associated with the non-medullated fibers.

Menstruation.—This consists of a hemorrhagic and mucous discharge from the uterus, which recurs about every twenty-eight days in the non-pregnant woman between the ages of thirteen and forty-five. It is accompanied by more or less severe systemic disturbances of a neurotic nature, and also by increased activity of the glandular system as a whole.

Enlargement of the thyroid gland usually accompanies the menstrual flow.

From five to ten days before the menstrual flow begins there is a marked hyperemic condition of the

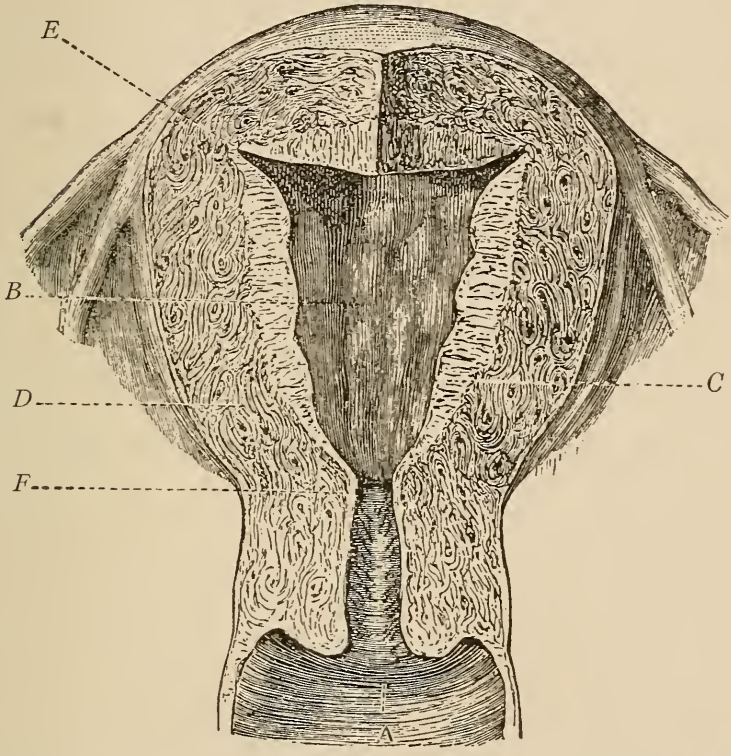


Fig. 234.—Uterus during menstruation, cut open to show the swelling of the whole organ, and particularly the mucous membrane: *A*, Mucous membrane of cervix; *B*, *C*, mucous membrane of corpus, much thickened; *D*, muscular layer; *E*, uterine opening of tube; *F*, os internum (the mucous membrane tapers down to these openings) (Courty).

uterine wall. The congestion of blood causes a marked swelling and growth of the uterine mucosa, so that it attains a thickness of 6.0 mm. This mucosa is then called the *decidua menstrualis*. After these changes have occurred the menstrual flow be-

gins and usually lasts for four days. This results in a complete or partial exfoliation of the superficial part of the mucous membrane of the uterine fundus and body, but does not involve the cervix. The exfoliation begins at the internal os and advances progressively toward the fundus. The restoration of the mucosa proceeds in the same order, from below upward, and in the course of five or six days the mucous membrane is restored. The epithelial lining regenerates from the free ends of the mucous glands that did not partake in the exfoliation.

The uterus is thus a seat of great physiological activity. During at least one-half the menstrual period of twenty-eight days there are marked structural changes manifest in the uterine mucosa. In such an active organ pathological disturbances are naturally of frequent occurrence.

Menstruation and ovulation are related phenomena, and yet there is evidence that neither one depends on the other. Pregnancies may occur before the menstrual period is inaugurated. Even at the early age of nine years pregnancy has been reported; also in mature women after confinement, but before menstruation has reappeared, pregnancy may occur. A woman who does not menstruate does not become pregnant, as a rule, but there are exceptions. Ovulation, therefore, may go on without menstruation, and there is evidence that menstruation may prevail without ovulation. For a further discussion of this subject, see Raymond's "Human Physiology."

PREGNANCY.

During pregnancy the mucous membrane of the uterus becomes modified into a membrane called the *decidua graviditatis*. This membrane may be divided into (1) the *decidua serotina* or *basalis*, that part of the mucosa to which the ovum is attached and in which the placenta develops; (2) the *decidua reflexa*, that which envelops the ovum, and (3) the *decidua vera*, the part that lines the rest of the uterus.

In the early stages of pregnancy the changes in the uterine mucosa resemble those of the decidua menstrualis. At the end of the first half of pregnancy the decidua serotina is 1 cm. thick. The epithelial lining has disappeared and two layers can be recognized: (1) a superficial *compact layer*, and (2) a deep *spongy layer*. The *compact layer* consists of connective-tissue elements and some very large pigmented cells called the *decidua cells*. These cells usually have one large nucleus, but some of them may be polynucleated. The cells are thirty to one hundred μ in diameter, and oval or elongated, resembling epithelial cells, although they are supposed to develop from the interstitial connective-tissue cells of the normal mucosa. They are of diagnostic value in uterine curetments where they become a probable evidence of pregnancy. In post-mortems they have no medico-legal significance, as these cells may be found in the decidua menstrualis. In the *spongy layer* the connective-tissue cells form septa between the flattened and sacculated as well as tor-

tuous mucous glands. Blood-vessels also form a plexus in the spongy layer.

The decidua reflexa disappears during the first months of pregnancy, while the decidua serotina enters into the formation of the placenta.

Placenta.—The placenta is a vascular organ for the nourishment of the fetus, and serves the purpose of bringing the fetal and maternal blood into closest proximity without actually blending. The organ

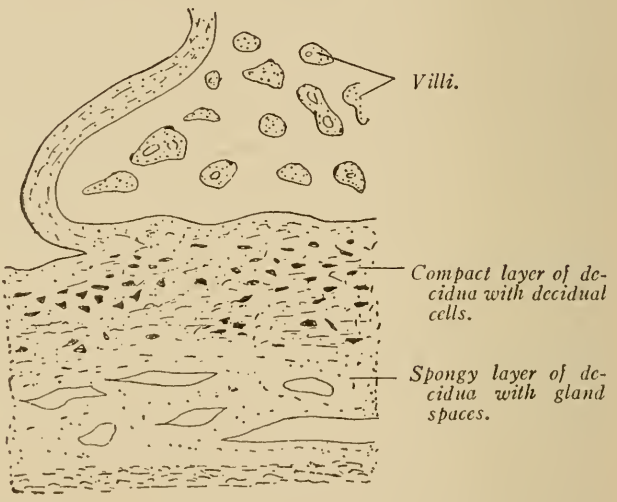
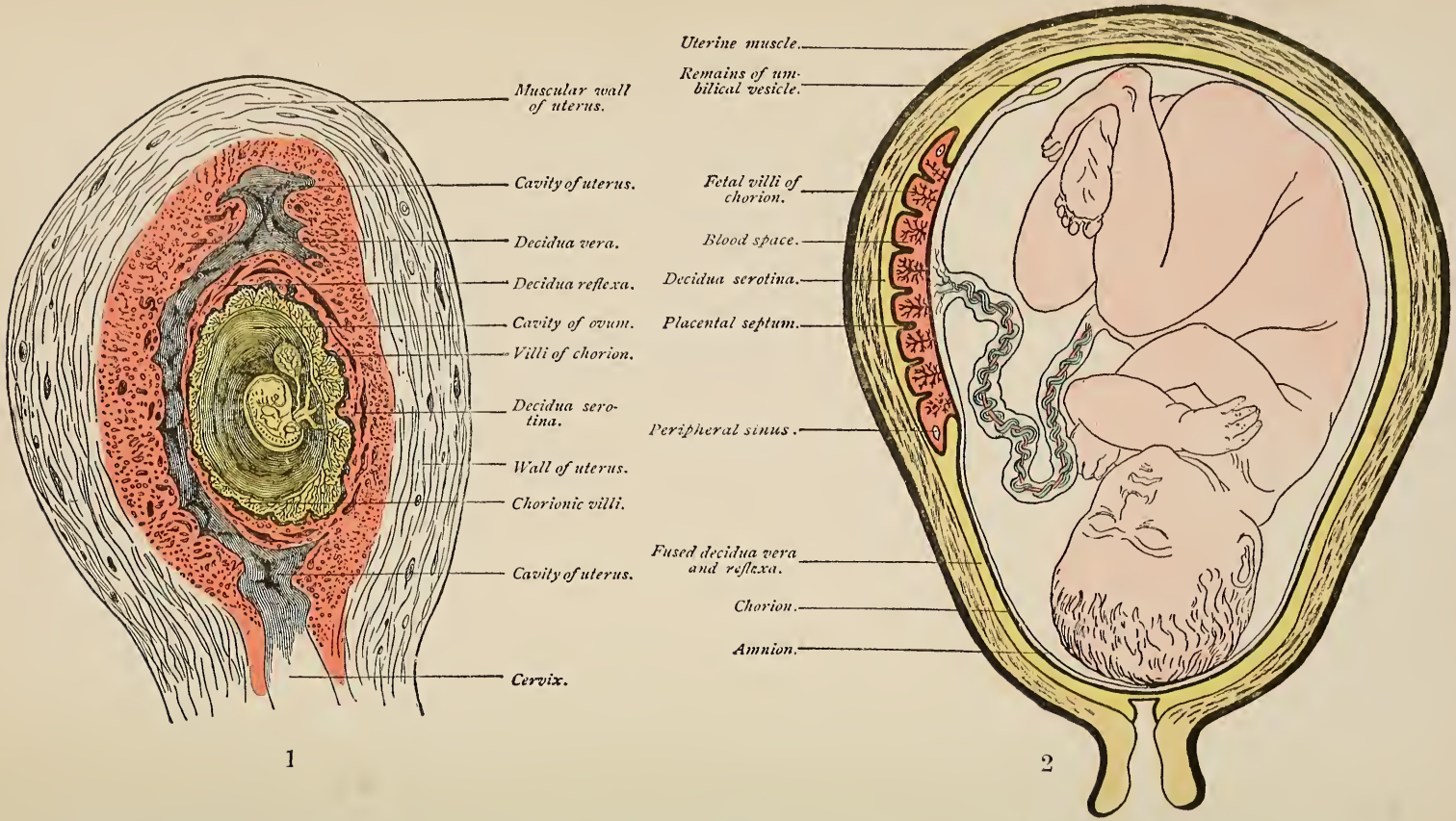


Fig. 235.—Section of the decidua serotina at the margin of the placenta.

may be divided into an embryonic part, the *placenta fœtalis*, and a maternal part, the *placenta materna*. The latter is the modified uterine mucosa or decidua serotina.

The fertilized ovum usually finds lodgment in the fundus of the uterus. Very early it becomes enclosed in an envelope of its own production called the *chorion*. This chorion has an outer epithelial

PLATE V.



1. Semi-diagrammatic section of gravid uterus, showing contained ovum of about five weeks (modified from Allen Thomson).
2. Semi-diagrammatic section of uterus, showing relations of fetal and maternal placenta (Ahlfeld).

layer and an inner connective-tissue layer, the latter being vascular. It is this vascular chorion that enters into intimate relations with the uterine mucosa to form the placenta, the former the fetal part and the latter the maternal part. These parts become intimately associated.

The chorion very early produces a large number of villi which invade the mucosa, where they ultimately become large and much branched, like the root of a tree. These are the chorionic villi and belong to the fetal placenta. Each villus consists of a connective-tissue core with an epithelial lining. The fetal blood circulates through the connective-tissue core while the maternal blood bathes the external surfaces of the villi. The terminal ramifications of each villus becomes firmly anchored in the uterine mucosa, while the branched lateral twigs float freely in the maternal blood spaces or *intervillus sinuses*. These villi serve a double purpose. They attach the fetal placenta firmly to the uterus, and establish a close relation between fetal and maternal blood whereby the embryo receives proper nourishment. Upon closer examination each villus should present in cross section an outer layer of simple squamous

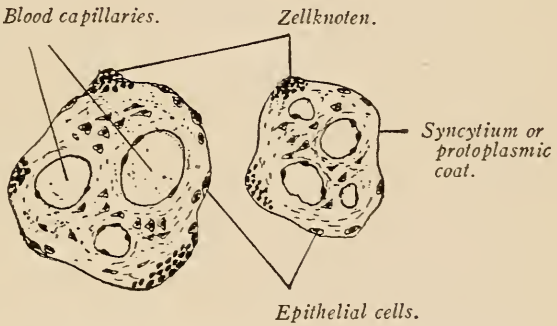


Fig. 236.—Cross section of two human chorionic villi at end of pregnancy.

epithelial cells and a core of connective-tissue cells in which two or more small capillary blood-vessels ramify. The epithelium of the villi undergoes great alterations and may entirely disappear, to be replaced by isolated accumulations of large round nuclei that stain intensely with nuclear dyes, and that form protuberances on the surfaces particularly of the large villi. These are called *zellknoten*, or cell knots. Their origin and significance is doubtful. In the earlier months of pregnancy the epithelial investment of each villus is clothed externally by a continuous protoplasmic mass, called the *syncytium*, containing small and irregularly scattered nuclei. It is generally supposed that the syncytium represents the modified and disintegrated uterine epithelium and is therefore of maternal origin. Some embryologists affirm that in some villi there is a membrane external to the syncytium which morphologically represents the epithelial wall of the uterine blood-vessels. The maternal blood, however, very soon breaks through the capillary spaces of the uterine mucosa and enters the intervillus sinuses clothed by the syncytium. The fetal circulation is a closed system and *nowhere is there a direct intermingling of fetal and maternal blood.* Theoretically the exchange of gases, in the early stages of development, takes place through (1) the epithelial wall of the maternal capillaries; (2) the uterine epithelial lining, probably represented by the syncytium; (3) the epithelial lining of the chorion, and (4) the epithelial wall of the fetal blood capillaries. The first of these membranes is not always

PLATE VI.

DIAGRAMMATIC SECTION THROUGH THE HUMAN PLACENTA AT THE MIDDLE OF THE FIFTH MONTH (after Leopold).

The fetal placenta, consisting of the chorion (*m*) with its villi (*z*), has grown into the maternal placenta; the villi present attached portions (h^1, h^2) and free processes (*if*); *sp* is the spongy layer of the decidua serotina, in which the separation takes place along the line *Tr*; *CS* is the compact layer forming the inner part of the uterine placenta, which consists of the basal plate (*BP*), the closing plate (*SP*), the arteries (*a*), the cavernous blood-spaces (*c*), and the marginal sinus.

present, as maternal blood ruptures this wall. The second investment, or syncytium, disintegrates. The third also disappears, at least in parts, or becomes so thin that it can scarcely be detected. Ultimately, therefore, the fetal and maternal blood is practically separated by only one membrane, the epithelium of the fetal capillaries.

The maternal placenta does not differ structurally from the histology of the decidua already described except in degree of complexity. There is an internal compact portion and a deeper spongy layer. The latter rests against the uterine muscularis and is very vascular. Numerous blood-vessels penetrate the compact layer to open freely into the intervillus sinuses already described. These blood-vessels usually take a very tortuous course, and they are thus able to adjust themselves to contractions and expansions of the uterine wall. Decidual cells are especially conspicuous in the compact layer of the placenta. These cells are sometimes present in the spongy layer but never in the chorionic villi or fetal portions of the placenta.

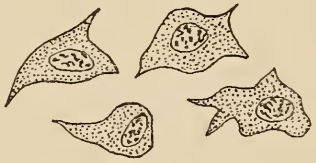


Fig. 237.—Four decidual cells from decidua serotina.

The fetal blood reaches the placenta through the umbilical cord. There is regularly present two arteries and one vein, imbedded in a gelatinous connective-tissue matrix known as *Wharton's jelly*. The blood in the arteries is carried to the placenta and is venous. That in the vein returns from the placenta and is arterial. After birth, when the pla-

centa comes away, it is always at the expense of the uterine mucosa, which leaves a raw, bleeding surface. The uterine muscles at once contract, reducing the uterine cavity and checking the hemorrhage. A normal mucous membrane at once regenerates, the ciliated epithelium and mucous glands developing from remnants of glands that were not entirely obliterated by the placental growth. As a rule regular menstruation is inaugurated when lactation ceases, but there are exceptions to this. A second pregnancy may follow without any intervening menstrual period, but this is rare.

THE MAMMARY GLAND.

The mammary gland is a skin gland that is present in both sexes. In the second month of embryonic life there is a linear thickening of the skin, extending from each axilla to the groin, and at regular intervals in this ridge a series of mammary glands develop in many vertebrates. In the human race only one pair is produced, which represents the fourth or fifth pair of this series. In rare cases accessory mammary glands are found in man both above and below the normal pair.

In childhood the mammary gland is identical in both sexes, but with approaching puberty it enlarges in the female, reaching its highest development at the end of pregnancy. The menopause brings about a retrogression and shrinkage of the organ. The gland is therefore to be considered an accessory sexual organ.

The mammary gland is a segregation of fifteen to

twenty separate compound tubulo-alveolar glands which open separately on the nipple by an equal number of pores. These glands are arranged radially and enclosed by a variable supply of fat and connective tissue in such a way that it is possible to divide the breast into fifteen to twenty lobes, which may be further divided into lobules. Each pore leads to a narrow vertical tube, the *lactiferous duct*, which widens just below the base of the nipple to form a receptacle called the *milk sinus*, beyond which it again becomes a narrow tube. The latter becomes branched to form *interlobular ducts* that open into distal dilatations or alveoli, which constitute the secreting portions of the gland.

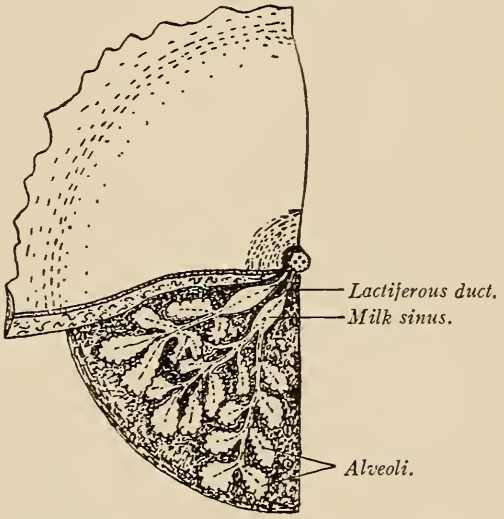


Fig. 238.—Diagram of one-half of mammary gland, dissected to show gland.

The lactiferous ducts and sinus are lined with simple columnar epithelium, which becomes stratified near the orifices where it is directly continuous with the stratified epithelium of the skin. The finer structure of the alveoli varies according to the functional activity of the organ. During lactation the alveoli are distended with milk. The cells of the

simple glandular epithelium become distended with the products of secretion that consist of granules and deposits of fat. The granules liquefy and along with the fat globules are discharged into the alveoli as milk. Many particles of fat are taken up by migrating white corpuscles, called phagocytes, which mix with the secretion and thus become converted into the *colostrum corpuscles* of early lactation. The gland cells after secretion accumulate a second sup-

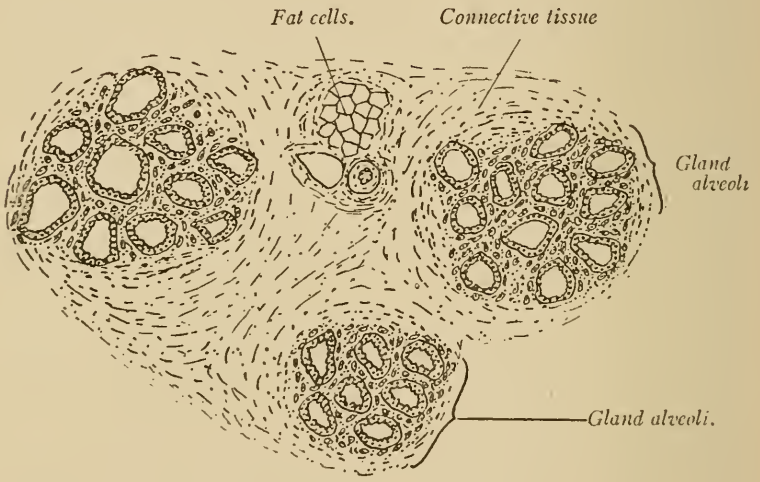


Fig. 239.—Section of a portion of the mammary gland.

ply, and this process is repeated many times. The secreting cell does not disintegrate as is the case in the sebaceous glands of the skin.

When the gland is not engaged in the secretion of milk, many of the alveoli shrink up and disappear, while the remaining ones become much reduced in size, and the gland as a whole is smaller. The cells of the alveoli become columnar, resembling the cells that line the ducts. The epithelium rests upon a

basement membrane and a *membrana propria*, the latter containing *basket cells* whose processes mingle with the glandular epithelium.

The interstitial tissue just external to the alveoli is composed of connective-tissue cells that stain heavily with nuclear dyes, while in the intervening spaces between the alveoli, connective-tissue fibers and fat cells are abundant. A supply of plain muscle fibers intervene and surround the ducts in the nipple. The fibers placed longitudinally function in the erection of the nipple, while the circular ones constrict the ducts.

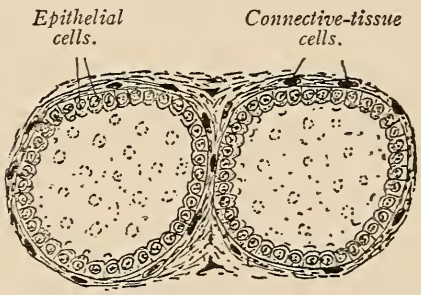


Fig. 240.—Section through two alveoli of mammary gland.

The nipple does not develop until after birth. Its normal position is in the fourth intercostal space, about four inches from the sternum. It is clothed with stratified pigmented epithelium and devoid of hair follicles and sweat glands. The skin immediately around the nipple is also pigmented, forming an *areola* with numerous small papillæ, giving a rough or wrinkled appearance. Besides large sweat glands, twelve or more large sebaceous glands, called *glands of Montgomery*, are present in this area. These glands open at the apices of the small papillæ just mentioned, and are usually considered as accessory milk glands.

Vessels and Nerves.—The *arteries* that supply the breasts are the *long thoracic*, the *internal mammary*,

and the *intercostals*. These anastomose freely and approach the gland from all directions. The *veins* are equally extensive. They accompany the arteries and bear the same names. *Lymphatics* are very numerous and form extensive lymph spaces around the alveoli of the gland. For the most part they drain to the lymph glands in the axilla, but from the deeper part of the breast they drain along the course of the internal mammary artery.

CHAPTER X.

THE SKIN.

The skin covers the entire body and is directly continuous with the mucous membranes of the alimentary canal and urogenital organs at their external orifices. It contains sensory nerve endings and in the deeper layers there is a liberal supply of both blood- and lymph-vessels. It is the chief factor in regulating body temperature, and is an efficient mechanical protection to the deeper tissues, while the sweat and sebaceous glands render it an important excretory organ. Hairs and nails represent modifications of the superficial layers. It varies considerably in thickness, being 4 mm. thick on the palms of the hand and 0.5 mm. over the back and shoulders. The color is imparted by pigmentation and the blood supply. The color is characteristic of races and variable in the different parts of the body as well as subject to modification depending on age and disease. The skin moves freely upon the deeper tissues, excepting over bony prominences where it is more firmly attached. On the palm of the hand and the sole of the foot it is also bound down to the subjacent tissues. The external surface presents in places numerous permanent ridges which correspond with rows of underlying papillæ, and which in criminals are utilized for the purposes of identification. The

hair follicles appear with regularity in external depressions practically all over the body, forming distinctive patterns. Cutaneous blood-vessels and

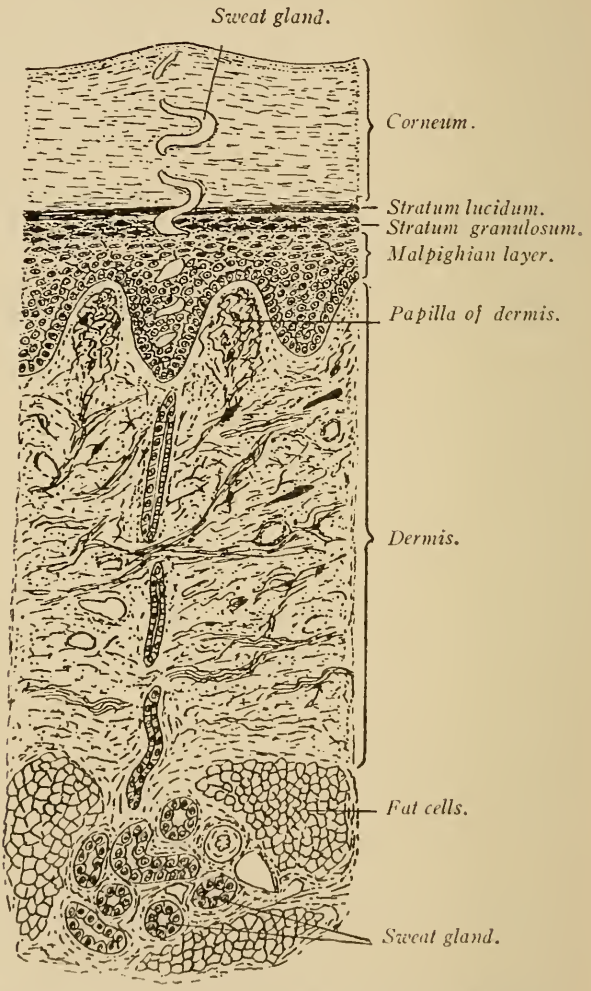


Fig. 241.—Section of skin through palmar surface of fingers.

tendons form ridges and lines readily detected by the unaided eye, and over which the skin is freely movable.

Structurally the skin or integument consists of two chief strata that may be subdivided into layers in the following manner:

I. Epidermis epithelial layers derived from the ectoderm.

1. Corneum or horny layer,—superficial epithelial plates.
2. Stratum lucidum,—absent where the skin is thin.
3. Stratum granulosum,—absent where the skin is thin.
4. Malpighian or germinal layer,—nucleated growing cells.

II. Dermis or corium,—connective-tissue elements from the mesoderm.

1. Papillary layer.
2. Reticular layer.

Epidermis.—The *horny layer* of the epidermis forms the outer covering of the skin and consists of several layers of scaly epithelial cells in which the nuclei have disappeared. The cells are dead and constantly exfoliating superficially, while new strata are regularly added from below. Bacteria are usually present in its external parts, and in surgical operations, therefore, the skin is thoroughly scrubbed, a process that removes most of this layer and renders the field of operation practically sterile. At birth the horny layer is less compact and of a red color. It is then called the *vernix caseosa*, which exfoliates in a few days, when the complexion

changes to that of the particular race to which the child belongs.

The *strata lucidum* and *granulosum* are two thin layers that lie between the corneum and the Malpighian layers and are best developed in the sole of the foot and the palm of the hand. Each consists of two or three rows of epithelial cells. The stratum lucidum overlies the stratum granulosum and is a refractive layer consisting of cells with disintegrating

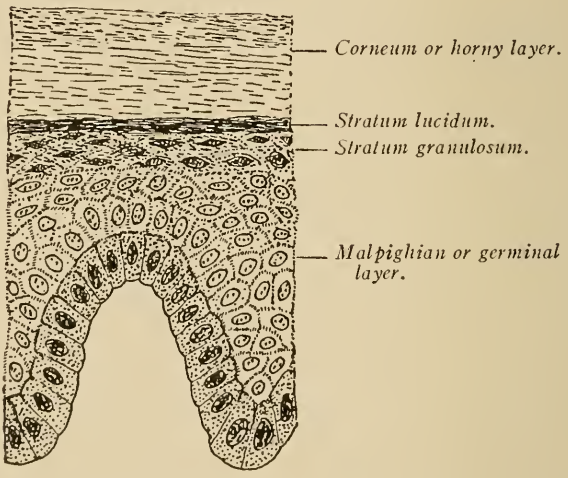


Fig. 242.—Section of epidermis of skin from palm surface of finger.

nuclei, and possessing a homogeneous substance called *eleidin*. The latter is colored with eosin but does not take nuclear dyes. The cells that compose the stratum granulosum possess many granules called *keratohyalin granules*, which are regarded as products of cell disintegration. These granules increase in size and coalesce to form the semifluid substance called eleidin of the stratum lucidum. The granules take nuclear dyes; the eleidin does not.

The *Malpighian layer* is made up of growing epithelial cells and constitutes the deeper parts of the epidermis. Its lower surface is beset with numerous depressions that receive connective-tissue papillæ from the dermis. The epidermis and dermis thus interlock by means of an extensive system of papillæ from each layer. The Malpighian layer is thicker than the horny layer, excepting in the sole of the foot and the palm of the hand. It consists of ten to fifteen layers of epithelial cells. The cells in the lower row are columnar and are so arranged that their long axis is vertical to that surface. In colored races these cells are pigmented and impart to the skin the particular color of the race. Pigmentation has been discussed on page 73, to which the reader is referred. The other cells of the Malpighian layer are cubical or flattened and so placed that their long axis lies parallel to the surface of the body. The cells of the deeper strata have numerous minute short processes and have been called *prickle cells*. These processes form intercellular bridges, which give rise to a complex system of minute intercellular channels that permit more freely the passage of nourishment. These cells are constantly dividing and adding new strata to the horny layer that is exfoliating at the same rate.

The **dermis, corium,** or **cutis vera,** is of connective-tissue origin and lies just beneath and intimately associated with the epidermis. It may be divided into a *papillary portion*, next to the epidermis, and a deeper *reticular portion* which shades off into the subdermal fascia. The papillary portion consists of

vascular and nerve papillæ that fit into depressions on the lower surface of the epidermis. The two layers of the dermis pass into each other without any sharp line of demarcation. In both layers there is an abundance of connective-tissue fibers, both elastic and non-elastic, forming what has been termed *areolar tissue.* These fibers form bundles that interlace to produce a network, particularly in the reticular or deep portions. In the meshes of this reticulum are to be found the bodies of the sweat glands, and a variable amount of adipose tissue, while hair follicles with their sebaceous glands find lodgment in the dermis with greater regularity. It is the dermis, and particularly the areolar tissue, that gives elasticity and mobility to the skin. The epidermis is not very elastic, consequently wrinkles of the epidermis are formed when the fat is absorbed, and also in old age, by shrinkage of the areolar tissue.

A variable amount of muscle is everywhere present in the dermis. Smooth muscle is associated with the hair follicles, forming the arrector pili muscle. In the face and neck voluntary muscle fibers may be traced into the papillary layer, while a third set of muscle elements is associated with the sweat glands. The latter is of the smooth variety and will be described along with the sweat glands.

The dermis everywhere is very vascular. Blood- and lymph-vessels ramify freely through it, but in no case do they enter the epidermis. Nerve fibers, on the other hand, enter the Malpighian layer of the epidermis and arborize around and between the epithelial cells. In the dermis these fibers form an

extensive nerve plexus, from which some terminal fibers proceed to the hair follicles, and others to special nerve papillæ in the dermis. These and other nerve terminations will be described as peripheral nerve endings in another chapter.

HAIRS.

The hairs are distributed practically over the whole surface of the body, with the exception of the palms of the hand, the soles of the feet, and the red border of the lips. They are distributed with considerable regularity, as a rule one hair for each follicle, but there may be two and sometimes three. The part of the hair buried in the skin is called the *root*, and the part that projects beyond the surface is the *shaft*. The lower part of the root is thickened to form the *hair bulb*, into which is pushed from below a vascular connective-tissue projection called the *hair papilla*. The root is inserted deep in the skin, usually reaching the subdermal elements. It is placed diagonally to the surface and becomes enclosed in a specially modified wall made up of several layers derived partly from the epidermis and partly from the dermis.

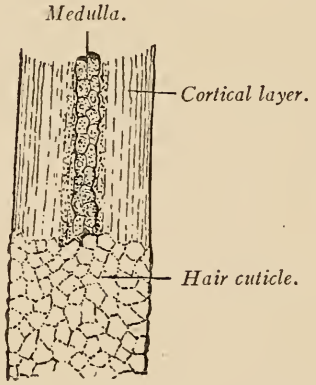


Fig. 243.—Portion of a hair.

Most hairs are composed of three layers: an outer *cuticle*, a middle *cortical*, and a central portion, the

medulla. In thin and light hairs the medulla is usually absent.

The *hair cuticle*, or outer *hair membrane*, is made up of structureless transparent epithelial scales that overlap each other in the direction of the distal end of the hair. A hair feels smooth, therefore, if pulled tnrough the fingers from the root to the free end. These scales overlap each other sometimes to such an extent that the cuticle has the appearance of being stratified. The scales are derived from epithelial cells that have become cornified, and they are thus closely related to the horny epithelial plates of the epidermis.

The *cortical substance* forms the main bulk of the hair and lies just beneath the cuticle. The cortex consists of spindle-shaped nucleated cells which show a distinct fibrillar structure, giving the whole hair the appearance of being longitudinally striated. Pigment granules are deposited in these cells and between them, to which the hair owes most of its color. Numerous small spaces filled with air are frequently formed between the cells of the cortical layer, and these give a white color to hairs that have a scanty supply of pigment. Hairs that have entirely lost their pigment and have none of these air spaces, are gray but not white.

The medullary substance forms the axis of the hair and may be absent, but is usually present in thick hairs. It is made up of nucleated cubical epithelial cells forming two or three rows in thickness. Pigment is also present in the medullary cells.

Hair Follicles.—The hair follicles are the pits in the skin occupied by the roots of the hairs. These pits are placed diagonally to the surface, and in the scalp where the skin is thick they are at least half an inch in length. It is estimated that the normal scalp has about one hundred and twenty thousand of these follicles, or an average of eight hundred to the square inch. Each follicle is really a minute tubular de-

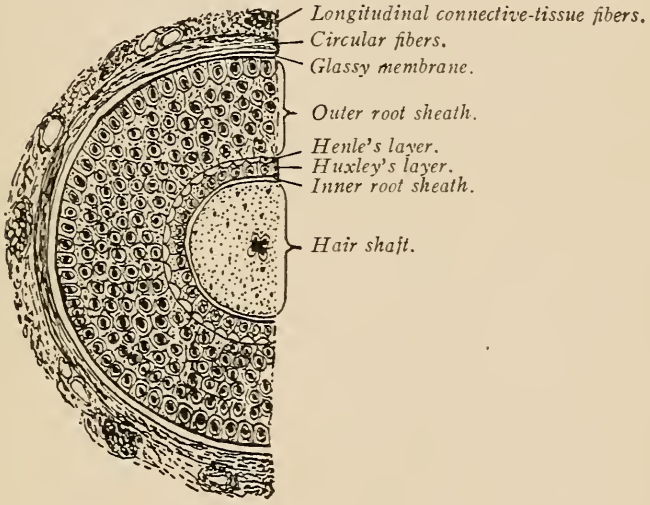


Fig. 244.—Cross section of a hair follicle.

pression or invagination of the skin, and its wall is therefore made up of constituents from both the epidermis and the dermis. These layers may be tabulated as follows:

I. Outer tunic.
   1. Connective-tissue fibers arranged longitudinally.
   2. Connective-tissue fibers, circular.
   3. Glassy membrane.

II. Outer root sheath; resembles Malpighian layer of the epidermis.

III. Inner root sheath.

1. Henle's layer,—non-nucleated elements.
2. Huxley's layer,—nucleated cells.
3. Root sheath,—structureless membrane.

The outer tunic is derived from the dermis and is of connective-tissue origin. Externally there is a layer of connective-tissue fibers arranged longitudinally, in which may be found a few connective-tissue cells and a delicate plexus of nerve fibers. The non-elastic connective-tissue fibers predominate, but the elastic variety is also present. Internal to the longitudinal fibers is a compact circular layer of non-elastic connective-tissue fibers, and internal to this is the *glassy membrane*, a very thin hyaline sheath often difficult to find. The outer tunic invests the lower half of the root sheath. This tunic, in the so-called *tactile hairs* of many mammals, has a rich nerve innervation and a liberal blood supply. In such hairs nerve fibers have been traced to the glassy membrane, while others apparently penetrate to tactile cells in the outer root sheath.

The *root sheaths* encase the root of the hairs and are derived from the epidermis, being therefore of ectodermal origin. The *outer root sheath* is a direct continuation of the Malpighian layer and diminishes in thickness toward the bottom of the follicle. It is composed of nucleated epithelial cells which possess intercellular bridges and a fibrillar protoplasm. This sheath always stains heavily with nuclear dyes.

The *inner root sheath* is less conspicuous, and in good sections will be found to consist of an outer layer of two rows of non-nucleated elements, representing cornified epithelial cells and called *Henle's layer*, and

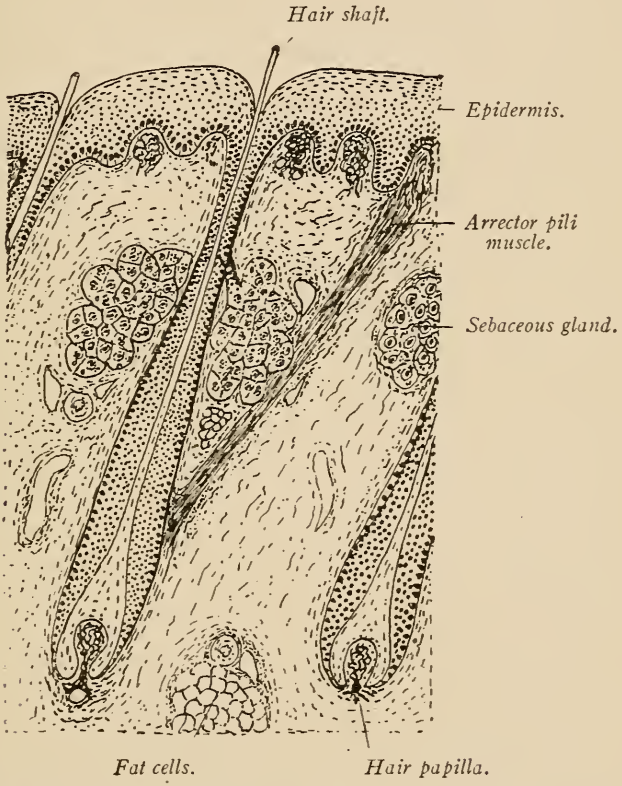


Fig. 245.—Cross section of the human scalp.

internal to this about two rows of nucleated cells, called *Huxley's layer*. These layers are absent from the upper half of the follicle. Internal to Huxley's layer, and in direct contact with the root of the hair, is the *root sheath*, which has much the same structure as the *hair cuticle*. Many scaly plates are imbricated

upon each other and interlock with those of the hair cuticle in such a manner that if a hair is pulled out the root sheath comes away with it, the break taking place along Huxley's and Henle's layers.

The *hair papilla* indents the lower end of the root and is of connective-tissue origin. It has a rich blood supply which contributes nourishment to the adjacent epithelial cells of the root which are constantly dividing. It is this cell division that brings about the growth of a hair. If the papilla is destroyed the hair dies. When a hair is pulled out with its root the papilla and some adjacent epithelial cells usually remain uninjured. The epithelial cells in due time reproduce a new hair.

The **arrector pili** muscle consists of bundles of smooth muscle fibers that pass obliquely downward from the upper surface of the dermis to be inserted in the connective-tissue tunic of the hair follicle near its lower extremity. The insertion of these fibers is always on the side toward which the hair inclines, so that when the fibers contract the root is drawn to a vertical position and the hair becomes erect.

The hair on the scalp grows approximately at the rate of twelve inches a year, or one inch a month. The average duration of a hair is about four years. Many vertebrates, as horses and cattle, shed their hair annually, every spring, a phenomenon called *moulting*. In mankind the hair of the scalp is constantly dropping out and being replaced by growths of new shafts. Occasionally hair grows where it normally does not belong and for cosmetic effect requires removal. This is done by electrolysis,

which consists in passing an electric needle down along the root of each hair to the hair papilla, which is then destroyed by a weak current of electricity. The hair is then readily removed and does not return. The loss of hair on the scalp is due to a variety of causes, many of which we cannot explain. It often accompanies a prolonged illness, such as typhoid fever, and is then doubtless due to a general emaciation resulting in lack of proper nourishment of the scalp. The loss of hair in such cases is only temporary. Certain neurotic diseases result in a permanent loss and the same may be attributed to some germ diseases of the scalp that infest and destroy the hair papillæ. In other cases baldness seems to be hereditary. It naturally follows that a healthy condition of the scalp will contribute to a rich growth of hair. Regular massage with a stiff brush no doubt accelerates the blood flow and thus brings about a better nourishment and growth to the hair.

The natural preservation of hair after death is well known. In Egyptian mummies the hair is well preserved even to its natural color. The hair is thus an important factor in the identification of unknown deceased persons.

THE NAILS.

The **nails** are epidermal structures that are morphologically analogous to the hoofs and claws of lower animals. Each nail may be divided into a *body*, the part that is exposed, and the *root* that is hidden from view and lies in a fold of the skin. The

lateral margins are also covered by a fold of the skin called the *nail wall.* The nails have a pink color imparted by the subjacent blood, excepting near the root, where there is an opaque area called the *lunula.* The lunulæ diminish in size from the thumb to the little finger.

Each nail rests upon a very vascular dermis which has been called the *nail bed* or *matrix.* This connective-tissue bed has many fine longitudinal ridges and alternating grooves which fit closely into corresponding grooves and ridges on the lower surface of the nail. Each nail consists of two parts: a deep soft stratum that represents the Malpighian layer of the epidermis, and an external hard cornified layer that

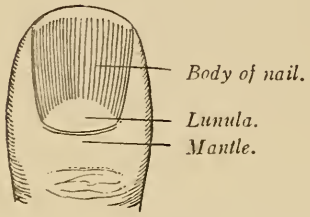


Fig. 246.—Thumb nail.

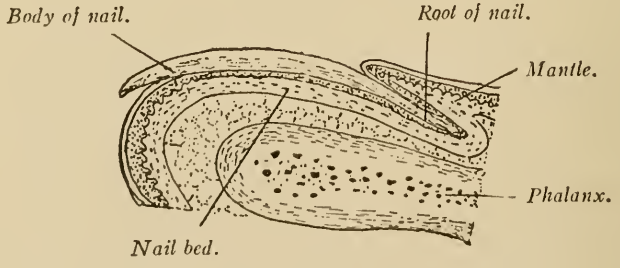


Fig. 247.—Longitudinal section of nail.

represents the horny layer. The former consists of nucleated polygonal prickle cells which fill the furrows and cover the nail bed several cells deep. It is affirmed that the cells of this Malpighian layer, in the distal part of the nail, do not produce any of the overlying horny material, but that growth of the nail

is exclusively due to epithelial proliferation from the Malpighian layer at the root of the nail and from that part directly under each *lunula* already described. A stratum granulosum is present in the upper portion of the matrix and absent in the other portions of the nail.

The external cornified layer consists of flat epithelial scales in which remnants of a nucleus may frequently be found. These scales are derived from epithelial cells and overlie each other, forming hardened lamellæ called *nail leaves*.

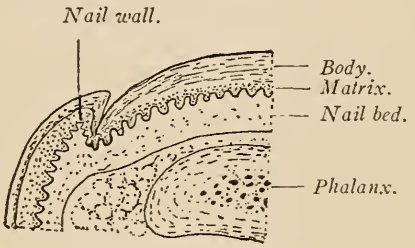


Fig. 248.—Cross section of nail.

The hoof of the horse corresponds to the fingernail of man, and is divided for descriptive purposes into the *wall*, the *sole* and the *frog*. The part which is visible when the foot rests on the ground is the wall, while the sole and frog are invisible in this position. As the human nail rests on a grooved matrix, so the inner surface of hoof wall is extensively folded into leaf-like structures which interlock or digitate with like growths from the enclosed connective tissue, those from the wall being called *horny* or *insensitive laminæ*, and those from the connective tissue or dermis the *sensitive* or *vascular laminæ*.

Horny Laminæ.—These are known collectively as the *keraphyllous tissue*, and clothing the inner surface of the wall dovetail with the sensitive laminæ

like interlocking leaves of two books. Each lamina extends approximately from the upper and inner margin of the hoof to its plantar border. There are from five to six hundred of these laminæ in each foot and they all increase in width from above to below. In a horizontal section of the hoof these laminæ appear like so many papillæ (Fig. 248*a*). From such a section it will be seen that along the sides of each lamina there are about sixty secondary folds, called *lamellæ*, by which the surface between sensitive and insensitive laminæ is enormously increased. These secondary leaves establish a fine series of longitudinal grooves along the lateral sides of each lamina, as seen in Fig. 248*b*. The surface lining of each horny fold consists of a single layer of cubical or low columnar epithelial cells analogous and continuous with the germinal layer of the skin. The cells are rich

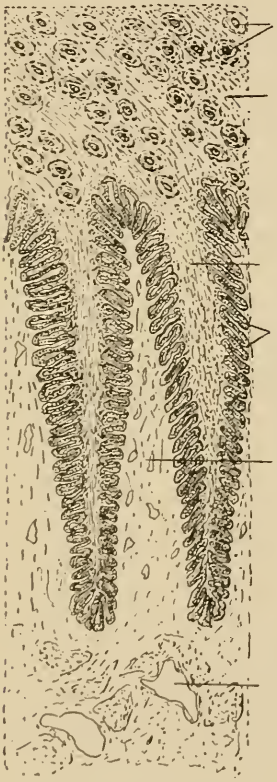

Horn tubes, epithelial cells.
Horn matrix, epithelial cells.
Insensitive laminæ, epithelial tissue.
Secondary laminæ or lamellæ lined by malpighian layer of epithelial cells.
Sensitive lamina connective tissue.
Blood-vessel.

Fig. 248*a*.—Horizontal section of hoof of horse.

in chromatin and are doubtless capable of active multiplication. A few scaly epithelial cells are always found in the body of each lamella, but in the substance of each lamina the tissue appears to be compact and of a fibrous variety. It is this compact tissue that is called collectively the *insensitive laminæ*. This fibrous tissue can be traced outward to the bases of the laminæ, where it mingles with and is ultimately lost in the epithelial horn wall of the hoof. While nuclei are absent, the tissue should be regarded as made up of scaly epi-

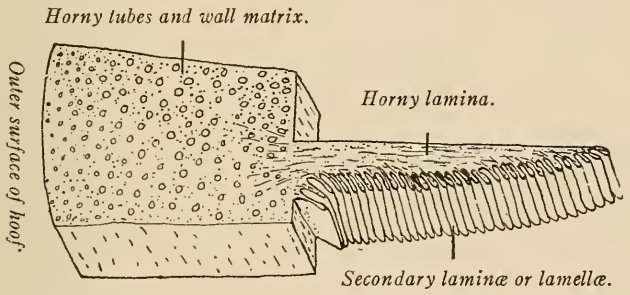


Fig. 248*b*.—Diagram of horizontal section through wall of hoof.

thelial plates so arranged as to give it a fibrous appearance very similar to the stratum lucidum of the human skin.

Vascular Laminæ.—These structures, collectively known as the *podophyllous tissue*, are leaf-like growths of the dermis, which interlock very snugly with the horny laminæ and lamellæ just described. They form an expansive fibrous and vascular tissue uniting the distal phalanx with the horny epidermal laminæ of the hoof. They are also called the *sensitive laminæ*, and, while the nerve endings in them have

not been worked out very carefully, it is reasonable to suppose that we have much the same structure as in the human nail-bed, such as free nerve endings, end-bulbs, and perhaps Rufini corpuscles.

Hoof Horn.—Like bone, this is tubular, resembling Haversian systems, but, unlike bone, it consists of *compact layers of epithelial cells*. As the human nail develops from the germinal epithelium at the root of the nail, so the wall of the hoof develops from similar epithelium that covers the *coronary cushion* situated at the upper margin of the hoof wall. This cushion has an abundance of epithelial papillæ, and from the surface of these papillæ cells proliferate to form the wall of the hoof tubes, while from the epithelium at the bases of these papillæ cells proliferate to form the hoof matrix. Thus, the hoof horn is exclusively an epithelial tissue, composed of flattened, scaly cells, with often an easily detected nucleus, cemented together compactly, their protoplasm being replaced by *keratin* granules, a protein-like substance very insoluble and containing 4.23 per cent. sulphur. The horn tubes extend downward from the papillæ of the coronary cushion and are parallel to each other. These tubes are smaller near the surface of the hoof and become larger in the deeper portion. The scaly cells of the tube wall are placed with their flat surfaces facing the tubes, that is, their long axes are perpendicular, while the long axis of the matrix cells are horizontal. This conforms to their origin, the former proliferating from the sides of the vertical coronary papiliæ, while the latter come from the horizontal coronary

surface between the bases of these papillæ. Fragments of epithelial cells may usually be found in the lumen of these tubes.

The laminæ just described provide an enormous surface of contact between the inner face of the wall and the external surface of the pedal bone. It is estimated that this surface is equal in area to eight or ten square feet in each hoof, and its chief function is doubtless to furnish support to the body weight of the horse. The sensitive laminæ thus act as an extensive and delicate cushion, tempering the jar sustained in walking or running. An inflammation of the sensitive laminæ is known as laminitis, a malady not uncommon in the horse.

The normal growth of the hoof is estimated at nearly one-half inch a month. Just how the horny laminæ move imperceptibly downward past the softer laminated structure is a subject of much speculation among veterinarians, but one on which opinions differ. It seems to me any sliding process is difficult to explain and that the solution sought is one of cell growth. During embryonic development it is easy to conceive of a rapid multiplication of the germinal epithelium, that is, the cells that form the membrane clothing the insensitive laminæ. Such a growth produces lateral pressure and accounts for the extensive folding of these laminated structures. In the adult foot the cells of the germinal layer show nuclei rich in chromatin, and being epithelial cells their multiplication continues through life. The horny laminæ, lying external to this layer, doubtless owe their origin, as well as their constant and regular growth, to the cells of

the *germinal epithelium*. In fact, embryologically this layer is to be considered as a part of the horny laminæ rather than interposed between the horny and the soft laminæ, as is done by most authors. The hoof wall, on the other hand, grows exclusively from the epithelial surface of the coronary cushion, and its downward progress is synchronous and uniform with the growth of the horny laminæ, as described above. The provisional horn that appears after removing a part of the hoof wall, surgically or otherwise, is explained as a cell proliferation of the germinal epithelium. If the human nail is removed this germinal epithelium is torn, but enough remains to proliferate epithelial cells in a few days which cornify to form a thin provisional nail analogous to the provisional hoof in a like injury to the horse's foot.

THE GLANDS OF THE SKIN.

Sweat glands are coiled simple tubular glands distributed over the whole surface of the skin, with the exception of the inner surface of the prepuce, the glans penis, and the red borders of the lips. In the axilla and around the anal opening they are exceptionally large and often branched. They are most numerous on the palm of the hand and the sole of the foot, where they number two thousand seven hundred to the square inch. On the forehead there are one thousand two hundred, and on the cheek about five hundred to the square inch, while over the back they are the least numerous. Their total number over the whole body has been estimated at nearly two million four hundred thousand, which, with an

average length of three-fourths of an inch, makes the united length approximately twenty-eight miles. This vast secreting surface is constantly secreting moisture, either as insensible or sensible perspiration. The amount of this perspiration within a given time

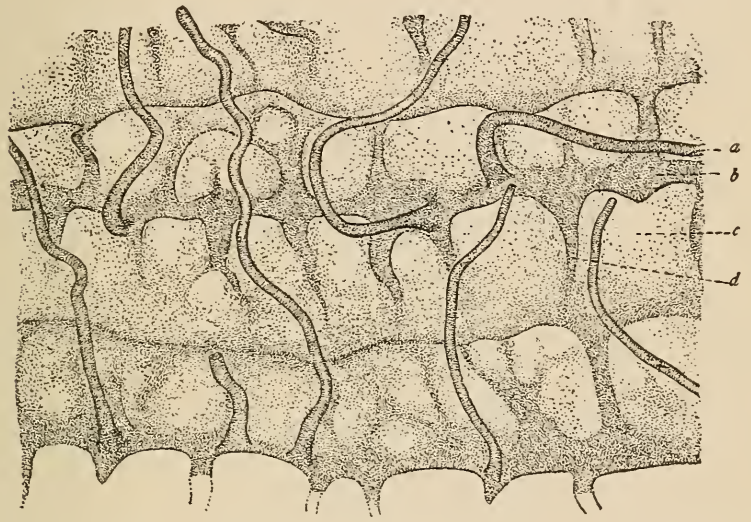


Fig. 249.—Under surface of the epidermis, separated from the cutis by boiling. The sweat glands may be traced for a considerable part of their length; *a*, Sweat gland ; *b*, longitudinal ridge; *c*, depression, *d*, cross ridge (Böhm and Davidoff).

varies considerably, but in the average person in good health it is estimated at about two pints every twenty-four hours.

The excretory ducts open on the surface of the skin by numerous sweat pores along the crests of the epidermal ridges. These pores may be seen with a low magnification or ordinary hand lens. The duct is spirally twisted in the stratum corneum and enters the dermis between two dermal papillæ; that is, at the apex of an epidermal papilla. In the dermis it takes a sinuous or nearly straight course and pene-

trates to the lower stratum of the skin, or even deeper, to the subcutaneous connective tissue. This distal end is very much coiled and constitutes the secreting portion of the gland. In the epidermis the duct has no other wall than the epithelial cells of the various layers through which it passes, but in the dermis the wall is composed of a single layer of short cubical cells outside of which there is a delicate basement membrane. The secreting portion is also lined by simple epithelium, but the cells are larger and have a finely granular protoplasm. Between the gland cells and the basement membrane there is found in the larger glands, a single layer of non-striated muscle cells arranged longitudinally. This muscle is derived from the ectoderm, while the other musculature of the body comes from the mesoderm. The muscle of the sweat glands probably aids these glands in expelling their products of secretion. Non-medullated nerve fibers of the sympathetic system form a delicate network just external to the basement membrane called the *epilamellar plexus*. From this plexus delicate fibers pass through the basement membrane to ramify between the gland cells, where they end in clusters of small terminal granules. The physiological activities of the sweat glands are thus directly under the control of the nervous system and do not depend on the

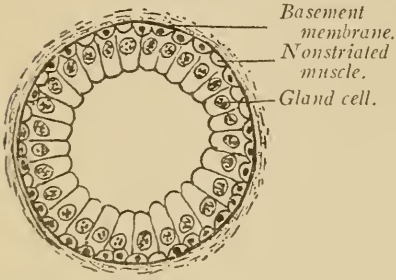


Fig. 250.—Cross section of deep portion of sweat gland.

blood supply, a fact that may also be demonstrated by physiological experiments.

Sebaceous glands are associated with hair follicles, into which they pour their contents. They are also found on the red borders of lips, the labia minora, the glans and prepuce, where hairs are absent. They are simple branched alveolar glands that secrete an oily substance called *sebum*. This is a

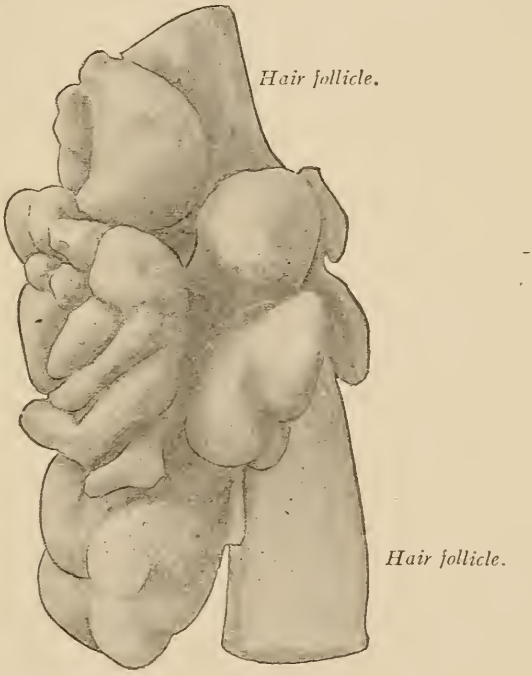


Fig. 251.—Model of a sebaceous gland with a portion of the hair follicle, reconstructed by Born's wax-plate method (Huber).

fluid at the temperature of the body, keeps the skin soft and flexible, and also supplies a natural dressing for the hair. In the scalp there may be an excessive secretion of sebum which dries and exfoliates with the horny epidermis as *dandruff*.

Each hair follicle has two or more sebaceous

glands that vary in size from 0.2 to 0.5 mm. The excretory duct is short and wide and opens into the upper third of the follicle. This duct is lined by stratified epithelium that is directly continuous with the outer root sheath of the hair follicle. The cells of the alveoli are very large and contain fat globules that vary in size and give a reticular appearance to the cytoplasm. The nuclei are relatively small. The cells completely fill the alveoli so that the latter appears to be solid. The cells disintegrate and change directly into secretion, which is then poured into the follicle as sebum. The renewal of lost cells takes place by constant proliferation of basal cells.

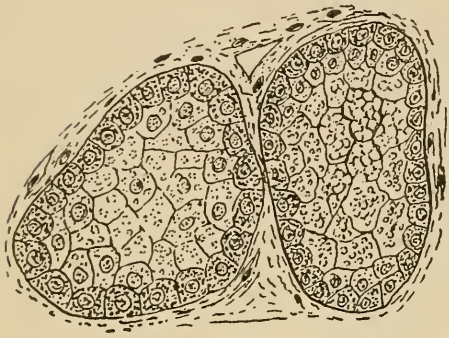


Fig. 252.—Section of two alveoli of a sebaceous gland.

It is quite common in the scalp to find sebaceous cysts, or wens, which result from an occlusion of the duct and an enlargement of the gland. These cysts are lined by a simple layer of epithelium and filled with a white, waxy, or semisolid fluid quite analogous to the sebum. Wens are of slow growth and cause no disturbance, unless they get very large or become infected by being carelessly opened. The radical cure consists in their complete removal, including the epithelial wall.

CHAPTER XI.

PERIPHERAL NERVE TERMINATIONS.

Physiologically, nerve endings may be classified as motor or sensory.

MOTOR NERVE ENDINGS.

(The Telodendria of Nerve Fibers in Muscle Tissue.)

1. **In Striated Muscle.**—The nerve endings in striated muscle are called *muscle-end plates*, or *sole plates*. In the higher vertebrates these are found in the muscle sarcoplasm just beneath the sarcolemma of each muscle fiber. A motor nerve fiber as it approaches its termination becomes much branched so as to innervate from ten to twenty muscle fibers. The axis cylinder enters the sarcoplasm where it immediately terminates in a web-like, flat end-brush with numerous dilatations. The axilemma, or Henle's sheath, is continuous around the brush. The medullary layer stops short at the level of the sarcolemma; that is, at the surface of the sarcoplasm. The neurolemma is continuous with the sarcolemma of the muscle fiber. The adjacent sarcoplasm of the muscle fiber is granular and a liberal supply of muscle nuclei is also present in the proximity, which results in an elevation of the muscle fiber at the point of nerve contact known as Doyer's elevation.

2. **In non-striated** and in **heart muscle** the nerve termination is more simple. The muscle is supplied with neurons from the sympathetic system, most of which are of the non-medullated variety. These fibers branch repeatedly to form an extensive

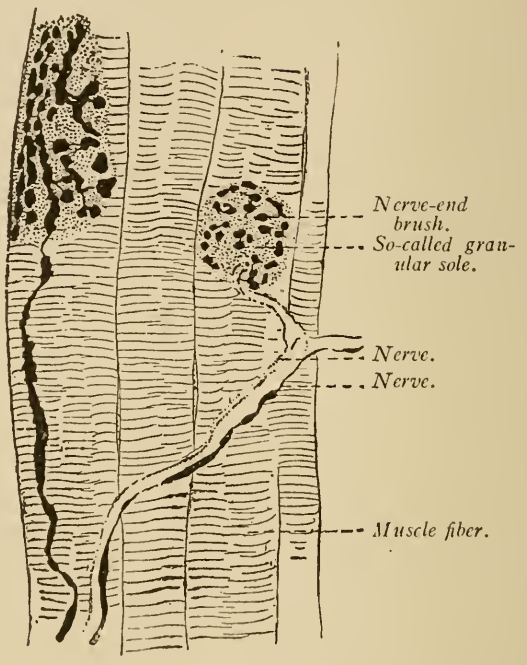


Fig. 253.—Motor endings in striated voluntary muscles. From *Pseudopus Pallasii*. As a consequence of the treatment the arborescence is shrunken and interrupted in its continuity. The end plate is in connection with two nerve branches (Böhm and Davidoff).

primary plexus surrounding the muscle bundles. From this plexus non-medullated fibers, that is, just the axis cylinders, penetrate the heart muscle, or the involuntary muscle, where they anastomose to form a delicate *secondary plexus*, from which lateral short twigs pass to end in minute dilatations or granules upon the muscle cells.

SENSORY NERVE ENDINGS.

(Telodendria of Dendrites.)

The sensory nerve terminations are essentially the terminals of dendrites as distinguished from the motor plates which are the terminals of axones. The cell bodies of these sensory neurons are found in the spinal and cranial ganglia, often at a considerable distance from the sensory termination. In

Fig. 254.—Motor nerve ending on heart muscle cells of cat; methylene-blue stain (Huber, De Witt).

Fig. 255.—Motor nerve ending on involuntary non-striated muscle cell from intestine of cat; methylene-blue stain (Huber, De Witt).

this case the dendrite is a long one, medullated, and structurally identical with an axis cylinder or axone. The nerve impulse is, however, normally carried toward the nerve cell, while in axones the impulse goes the opposite way. As stated in another place, such sensory neurons have a long dendrite that extends peripherally and a short axone that passes centrally; that is, to the spinal cord or brain.

These sensory endings form telodendria or end-brushes that vary in complexity according to the tissue elements that take part in their formation.

1. **Free Sensory Nerve Endings.**—These are the simplest forms of nerve endings and occur in epi-

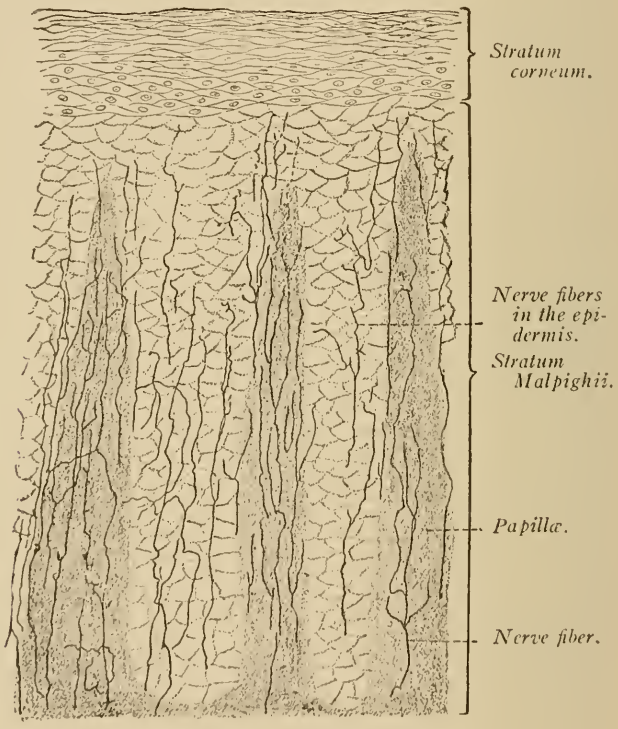


Fig. 256.—Nerves of epidermis and papillæ from ball of cat's foot (Böhm and Davidoff).

thelial tissues and in some parts of the connective tissues. The sensory nerve fibers near its termination repeatedly branch, the latter retaining the medullary sheath. The branches appear always at the nodes of Ranvier. From this coarse plexus a

finer non-medullated system of branches appear which innervate the epithelium and terminate in varicosities, discs, or minute granules that lie in apposition to epithelial cells. Similar free terminations occur in tendons, and ligaments, and other fibrous connective tissue.

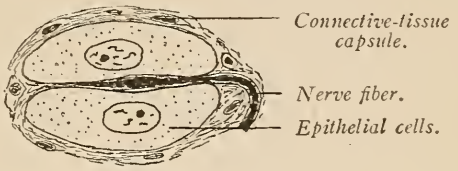


Fig. 257.—Tactile cells from the bill of a duck.

2. **Tactile Cells.**—These are also called *Grandry's corpuscles*, and may be found in the duck's bill just beneath the gum epithelium. The cells are of epithelial origin, oval, and measure about 50 μ in diameter. One to five cells are surrounded by a connective-tissue capsule. These cells are superposed on each other, with their long axes always parallel to the surface of the bill. A medullated nerve fiber may be traced to the capsule, which it penetrates and then becomes non-

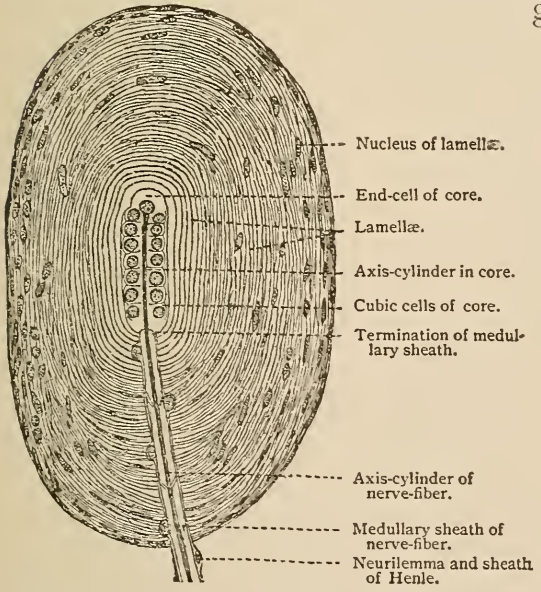


Fig. 258.—Corpuscle of Herbst from bill of duck (Böhm and Davidoff).

medullated. The latter terminates in *tactile discs* that are interposed between the tactile cells. A group of three cells will have two discs; five cells will have three discs.

3. **Corpuscles of Herbst.**—These are much larger bodies and may also be found in the bills of aquatic birds, in close association with the tactile cells just described. They are ovoid bodies 75 μ wide and 150 μ long. There is an inner core surrounded with connective-tissue lamellæ. The core contains the axis cylinder, which is thickened at the end and is encased between two rows of cells that seem to have the same function as Grandry's corpuscles. The nerve fiber enters at the end of the corpuscle and becomes non-medullated only after reaching the inner core.

Fig. 259.—Meissner's tactile corpuscle; methylene-blue stain (Dogiel, "Internat. Monatsschr. f. Anat. u. Phys.," vol. IX).

4. **Meissner's Corpuscles.**—These are found beneath the epidermis of man, particularly of the hand and foot, and occupy the dermal papillæ of the dermis.

They are oval bodies and approximately the same size as the corpuscles of Herbst. There is a thin connective-tissue capsule and a loose complex core. One or more medullated nerve fibers enter at the lower end of the corpuscle. These soon become non-medullated and their axones then make a variable number of spiral turns which interlace, branch, and are beset with many granules or varicosities. One or more axis cylinders occupy the center of the core.

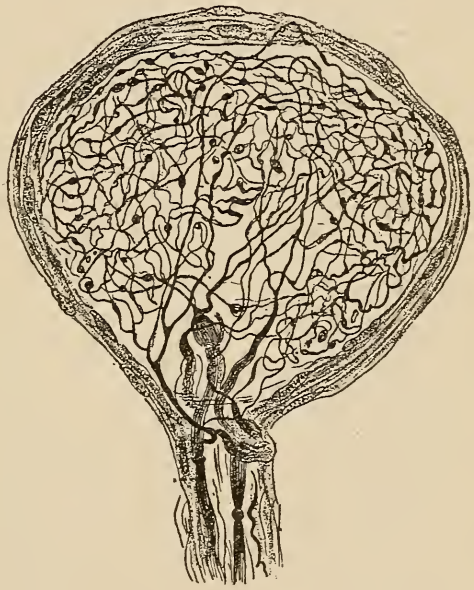


Fig. 260.—Genital corpuscle from the glans penis of man; methylene-blue stain (Dogiel, "Arch. f. mik. Anat.," vol. XLI.)

5. **Genital Corpuscles.** — These are oval or round bodies located in the mucosa, just beneath the epithelium of male and female genitalia. Their size varies from 0.1 mm. to 0.4 mm. They are surrounded by a thick fibrous capsule and each corpuscle is innervated by one to ten medullated nerve fibers. The latter become non-medullated after passing through the capsule, and the axones then form a complex core quite analogous to that of Meissner's corpuscle. In fact, the two are very similar structures.

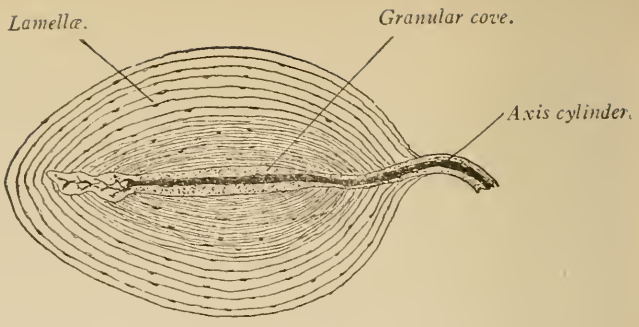


Fig. 261.—Pacinian corpuscle from mesentery.

Fig. 262.—Neuromuscular nerve-end organ from the intrinsic plantar muscles of dog; from teased preparation of tissue stained in methylene-blue. The figure shows the intrafusal muscle fibers, the nerve fibers and their terminations; the capsule and the sheath of Henle are not shown (Huber and De Witt, "Jour. Comp. Neurol.," vol. VII).

6. **Pacinian Corpuscles.**—These are oval bodies and the larger ones are easily visible to the naked eye, being over 2 mm. long. Structurally they seem related to the corpuscles of Herbst. They are found in the dermis of the hand and foot, particularly along the lower surface of the fingers and toes. They are also found in the joints, the peritoneum, pleura, pericardium, and are especially abundant in the mesentery. The greater portion of the corpuscle consists of concentric lamellæ of connective-tissue origin. Between these flat endothelial cells intervene. A granular core forms the axis of the corpuscle, in the center of which the axis cylinder may be traced. Usually one large nerve fiber goes to each corpuscle. After entering the core this forms a plexus of fine branches and becomes non-medullated.

Fig. 263.—Neurotendinous nerve-end organ from rabbit; teased preparation of tissue stained in methylene-blue (Huber and De Witt, "Jour. Comp. Neurol.," vol. x).

7. **Tendon and Muscle Spindles.**—A *tendon spindle* is an expansion of tendon bundles enclosed in a well defined connective-tissue sheath. The nerve fiber enters the middle of the spindle, divides re-

peatedly, becomes non-medullated and finally terminates in varicosities or expanded clavate ends. The *muscle spindle* is a collection of delicate muscle fibers enveloped in a dense perimysium sheath, the whole being innervated by sensory nerve endings much as in tendon spindles. The sensory endings both in tendon and muscle transmit the sensation of tension which becomes the basis for coördinate movements.

CHAPTER XII.

THE SPINAL CORD.

The *spinal cord* is an organ composed largely of neurons, with which are associated blood-vessels, connective-tissue elements, and a limited amount of epithelial and muscle cells. It represents the terminal portion of the cerebrospinal axis and is a direct continuation of the encephalon. It is one of the first organs to develop in the embryo where it makes its appearance as a dorsal ectodermal groove. This *neural groove* gradually closes to form a canal which lies at first just beneath the ectoderm and later becomes encased in connective-tissue layers and the bony axial skeleton.

The cord is bilaterally symmetrical and flattened dorso-ventrally. It presents two enlargements: (1) the upper or *cervical*, which extends from the third cervical vertebra to the second thoracic and corresponds to the origin of the nerves of the arm, and (2) the lower or *lumbar*, which extends from the ninth thoracic vertebra to the terminal cone at the level of the body of the second lumbar vertebra. The lumbar enlargement marks the origin of the nerves of the leg. From the apex of the terminal cone there extends a slender rudimentary prolongation, the *filum terminale*, which, with the spinal nerves of this region, is called the *cauda equina*. The

spinal cord, therefore, does not extend the whole length of the vertebral canal but only to the level of the second lumbar vertebra. Its length is about eighteen inches, its diameter one-half inch or less.

Membranes of the Cord or Meninges.—1. The *Dura*.—This is a thick strong membrane composed of

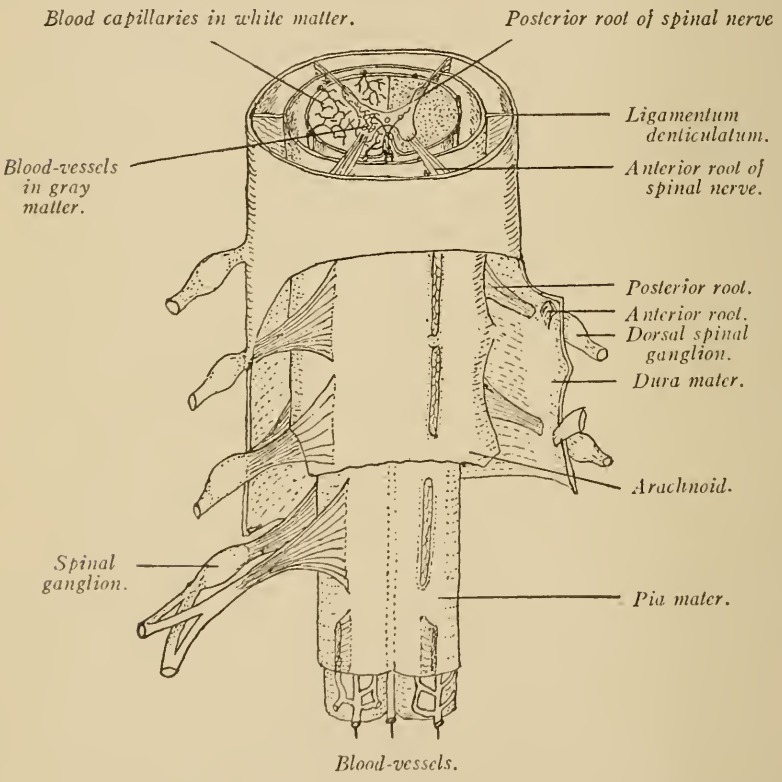


Fig. 264.—Portion of spinal cord and membranes dissected

white fibrous tissue which forms the outer covering of the cord. Many blood-vessels find lodgment in this membrane. It is analogous and continuous with the dura of the brain, the most striking difference being that the dura of the cord does not form

the internal periosteum of the vertebral canal. Between the dura and the vertebræ is a space called the *epidural space*, which is filled with areolar tissue, fat, and a plexus of spinal veins.

2. *The Pia.*—This is a thin connective-tissue layer that lies close to the surface of the cord, dips into the anterior fissure, and also sends fibers or trabeculæ into the cord substance. Many small blood-vessels accompany this layer.

3. *The Arachnoid.*—This is a delicate membrane between the other two, but much nearer the dura. Its external surface is clothed with a single layer of flat epithelial cells which secrete a serous fluid. The arachnoid is therefore a serous membrane.

Fissures.—1. *Posterior Median Fissure.*—This is a median dorsal fissure that extends the whole length of the cord. It is extremely narrow but deep, as it penetrates to the central gray matter, being intimately connected with the two sides in its course. The single septum is derived from the neuroglia tissue, and not from the pia, which sends no prolongation of any kind into it.

2. *Anterior Median Fissure.*—This also extends the whole length of the cord. It is shallower but wider than the posterior fissure and does not quite reach the central gray matter. The pia forms a fold into this fissure with which is associated many blood-vessels. The two median fissures or clefts divide the cord into a right and a left half, each practically identical with the other.

3. *Postero-lateral Groove.*—This is a shallow depression on each side of the posterior fissure and

marks the entrance into the cord of the dorsal roots of the spinal nerves. In a like position, anteriorly, is the exit of the anterior roots of the spinal nerves, but there is no depression or groove as in the case of the posterior roots. The two roots of the spinal nerves divide each half of the spinal cord into three regions or major tracts known as the posterior,

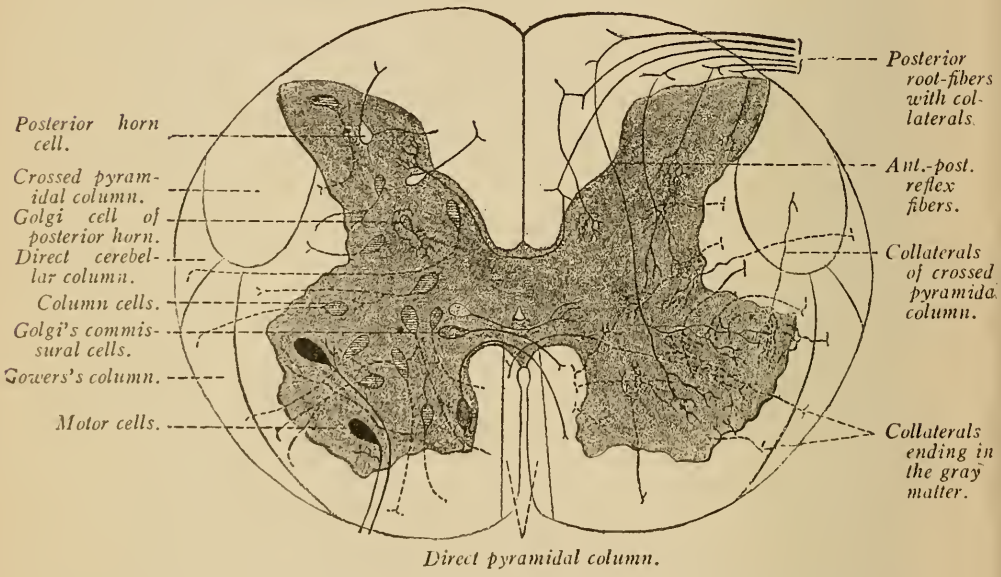


Fig. 265.—Schematic diagram of the spinal cord in cross section after von Lenhossék, showing in the left half the cells of the gray matter, in the right half the collateral branches ending in the gray matter (Huber).

lateral, and anterior columns. The posterior column is limited by the posterior fissure and the posterior roots, the lateral is the region between the roots, and the anterior lies between the anterior root and the anterior fissure.

Spinal Nerves.—Thirty-one pairs of nerves arise from the side of the cord. These are classified into

8 cervical, 12 dorsal, 5 lumbar, 5 sacral, and 1 coccygeal. Each nerve is attached to the cord by a dorsal and a ventral root. Each root, before uniting with the cord, breaks up into secondary bundles and spreads out like a fan, making a continuous linear attachment. The dorsal ganglion is located upon the dorsal within the vertebral canal, near the union of the two roots.

Gray Matter of the Cord.—The *gray matter* of the cord is centrally located and takes the form of a capital letter H. The gray matter in each lateral half resembles a crescent which is joined to the opposite side by an isthmus, in the center of which is the *central canal.* The latter is usually obliterated in the adult man, and is filled as well as surrounded by the *gelatinous substance of Rolando*, which is a reticular structure. That part of the isthmus above the central canal is called the *posterior gray commissure*, while the gray matter ventral to the canal is the *anterior commissure.*

Each crescent may be divided into a *posterior*, *lateral*, and *anterior horn.* The anterior horn is the largest and the lateral horn is the smallest. The *posterior horn* is pointed and approaches near to the posterior lateral groove. The apex of this horn is called the *zona terminalis.* At the base of this apex there is a reticular substance called the *zona reticularis*, while next to this and apparently capping the posterior horn is a gelatinous mass, similar to that which surrounds the central canal, called the *substantia gelatinosa of Rolando.*

The *nerve cells* of the posterior horn are irregularly

distributed and some of them are particularly small and have a stellate appearance. At the base and mesial surface of this horn there is a group of large nerve cells called the *column of Clarke*. This column extends from the second lumbar up through the dorsal region of the cord to the cervical. In the cervical region it is absent; however, *Stilling's nucleus* of this region may represent a remnant of the column of Clarke. At the base of the dorsal horn, deeper down and lateral to Clarke's column, another group of nerve cells may be found that is called *Waldeyer's central cell column*. This is reciprocal with Clarke's column; that is, in the dorsal region where Clarke's column is conspicuous, only remnants of Waldeyer's tract can be found, while in the other regions of the cord this cell tract is particularly prominent.

The *lateral horn* is a small lateral prominence at the side of the gray crescent. In the substance of this, a small collection of nerve cells may be found, while just beneath this the gray matter cuts into the white matter, forming processes called the *processus reticularis*.

The *anterior horn* is not only large but presents a blunt, rounded appearance. The nerve cells of this horn are very large and have been classified according to their position into antero-mesial, postero-mesial, antero-lateral, and postero-lateral. The axis cylinder of most of these cell bodies goes to form the anterior root of the spinal nerves. They therefore carry only motor impulses.

White Matter of the Cord.—The white matter of

the cord consists of medullated nerve fibers. Most of these fibers have no neurilemma, and the cord therefore is soft and pulpy, in contrast to the nerve trunks whose fibers have a neurilemma which with the connective-tissue elements make nerves tough and strong. The white matter practically encloses the gray. The fibers which compose it vary con-

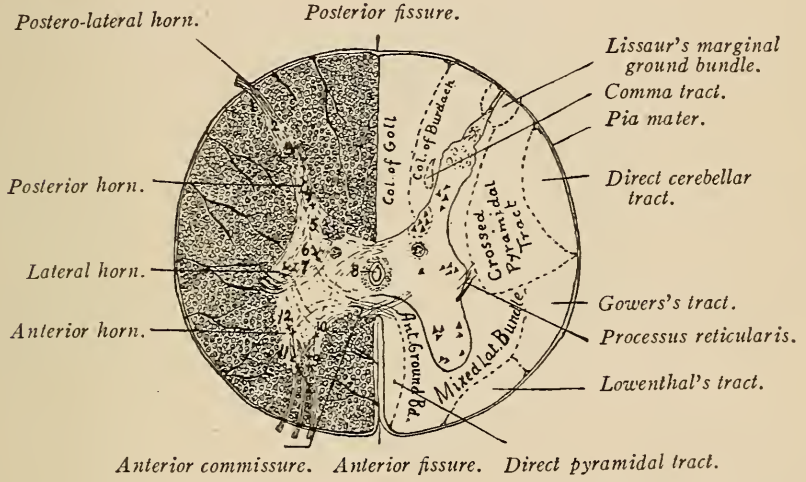


Fig. 266.—Cross section of the spinal cord, dorsal region. 1, Zona terminalis; 2, zona reticularis; 3, substantia gelatinosa of Rolando; 4, stellate cells of posterior horn; 5, column of Clarke; 6, Waldeyer's central cell column; 7, cells of lateral horn; 8, central canal; 9, antero-mesial cells; 10, postero-mesial cells; 11, antero-lateral cells; 12, postero-lateral cells.

siderably in size, both large and small being mixed up together. In sections of the adult healthy cord no evidence of definite tracts of fibers can be seen. We know, however, that longitudinally arranged groups of fibers run a definite course, have definite connections, and carry impulses that result in definite sensations and actions. The *physiological evi-*

dence of this fact is experimental and positive. A nerve fiber detached from its cell body dies. In this way tracts will degenerate in the cord, some above and some below a transverse cut. The *embryological evidence* rests on equally positive facts. In development certain tracts acquire medullary

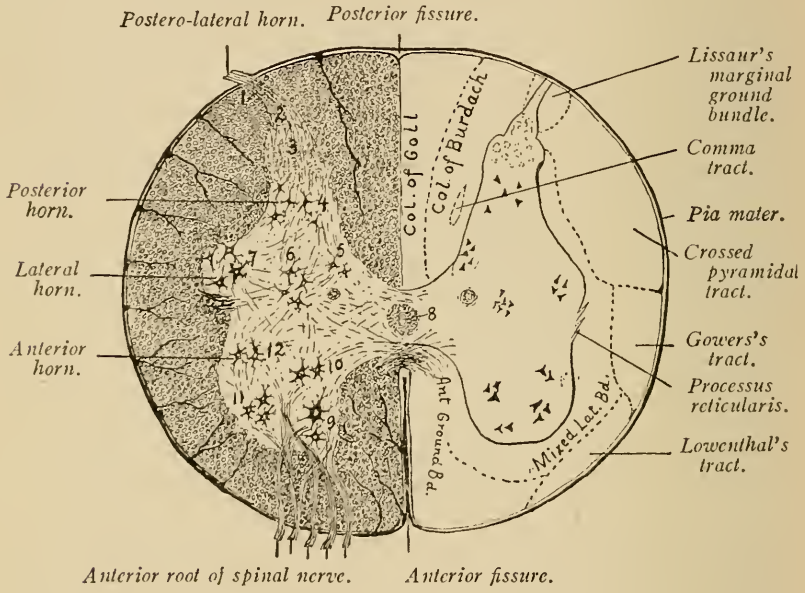


Fig. 267.—Cross section of the spinal cord, lumbar region. 1, zona terminalis; 2, zona reticularis; 3, substantia gelatinosa of Rolando; 4, stellate cells of posterior horn; 5, column of Clarke; 6, Waldeyer's central cell column; 7, cells of lateral horn; 8, central canal; 9, antero-mesial cells; 10, postero-mesial cells; 11, antero-lateral cells; 12, postero-lateral cells.

sheaths earlier than others. This fact has greatly extended our knowledge of the white matter in the cord. The *pathological evidence* is a third factor. Certain diseases produce degenerate lesions in the cord. Proper interpretations of these lesions have enabled us to map out definite nerve tracts in the cord, and to determine their relations as well as pos-

sible functions. The information evolved from these sources makes a classification of tracts, in the cord, possible.

Tracts of the Cord.—Posterior Region.

1. *Column of Goll.*—This lies adjacent to the dorsal fissure and extends the whole length of the cord. Its fibers arborize about nerve cells in the *nucleus gracilis* of the lower region of the medulla.

2. *Column of Burdach.*—This extends parallel to the column of Goll between the latter and the posterior horn of gray matter. It extends the whole length of the cord and its fibers arborize about nerve cells in the nucleus cuneatus of the medulla, adjacent to the nucleus gracilis. The column of Goll becomes wider in the upper portions of the cord and that of Burdach narrower. This is due to nerve fibers that gradually pass into the column of Goll from the column of Burdach on their way to the brain.

3. *Comma Tract.*—This is a small tract found in the column of Burdach, and represents sensory fibers from the posterior roots of the spinal nerves that pass down the cord for a short distance, and then turn into the anterior horn of gray matter to arborize about nerve cells of this region.

4. *Lissaur's Marginal Ground Bundle.*—This is a small commissural tract placed near the surface of the cord just lateral to the entrance of the posterior root fibers. It is formed by some of the fibers of this root. The tract extends the whole length of the cord, but each individual fiber runs but a short distance and then turns inward to arborize about nerve cells of the posterior horn.

These four tracts are composed almost entirely of nerve fibers that enter the cord by the posterior roots of the spinal nerves. They are therefore sensory tracts and forward impulses toward the brain. The termination of the posterier root fibers may be enumerated as follows:

1. Column of Goll, Burdach, comma tract, Lissaur's tract.
2. Arborize about the cells in Clarke's column.
3. Arborize about the cells in posterior horn.
4. Arborize about the cells in anterior horn on same and opposite side.

Lateral Region.—The tracts of this region are: (1) Direct Cerebellar; (2) Gowers's, or Ascending Antero-lateral; (3) Crossed Pyramidal; (4) Lowenthal's, or Antero-lateral Descending; (5) Mixed Lateral.

1. *The Direct Cerebellar.*—This is a band of fibers that lies at the surface of the cord just lateral to the dorso-lateral groove. Its nerve fibers are derived from the cells of the column of Clarke, consequently the tract extends from the last dorsal up to the medulla on the same side. It is an ascending or sensory tract, and, as it is traced upward, becomes wider from the acquisition of axones from the column of Clarke. It enters the cerebellum through the inferior peduncle and finally terminates in the cerebellar cortex of the superior worm on both sides, chiefly the opposite.

2. *Gowers's tract* lies just in front of the direct cerebellar and also at the surface of the cord. It is an ascending or sensory tract and some of its fibers are supposed to reach the cerebellum by passing

through the formatio reticularis of the medulla, and making a backward turn through the superior medullary velum of the same side.

Other fibers of this tract have been traced to the corpora quadrigemina, the thalamus, substantia nigra, and the lenticular nucleus of the cerebrum. The fibers of this tract extend the whole length of

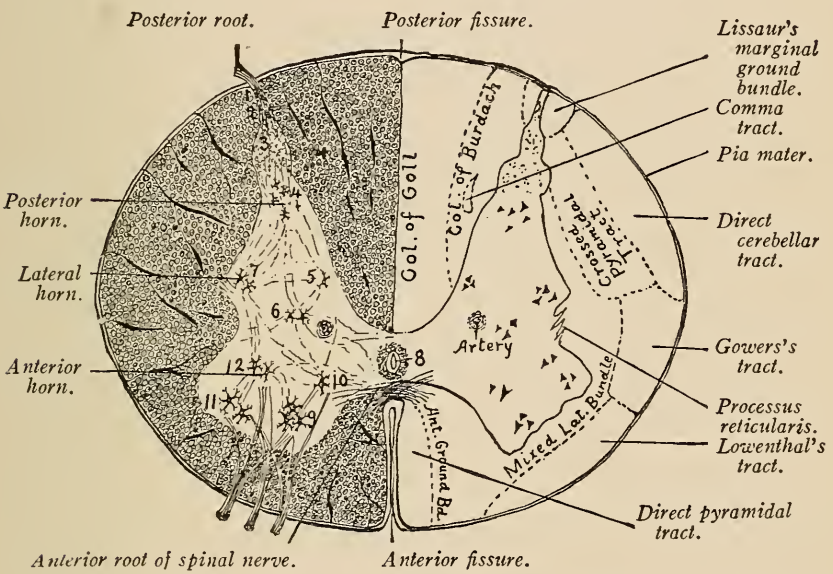


Fig. 268.—Cross section of spinal cord cervical region. 1, Zona terminalis; 2, zona reticularis; 3, substantia gelatinosa of Rolando; 4, stellate cells of posterior horn; 5, column of Clarke; 6, Waldeyer's central cell column; 7, cells of lateral horn; 8, central canal; 9, antero-mesial cells; 10, postero-mesial cells; 11, antero-lateral cells; 12, postero-lateral cells.

the cord and probably have their origin in the cells of the posterior horn.

3. The *crossed pyramidal tract* is a large and well-defined bundle that lies just beneath the direct cerebellar; that is, between this and the posterior horn. Below the point where the direct cerebellar

begins, the crossed pyramidal comes to the surface of the cord. The fibers of this tract have their origin in the large pyramidal cells of the cerebrum in the region of the area of Rolando. Traced downward from this source, they cross in the lower part of the medulla to the opposite side of the cord, making at this point the *motor decussation*. As it descends the tract gradually diminishes in size, due to the fact that fibers leave it to arborize around the large motor cells of the anterior horn. In this way the entire tract is ultimately exhausted near the lower extremity of the cord. It is thus a descending or motor tract that governs the opposite side of the body from where it has its origin.

4. *Lowenthal's tract* is closely associated with Gowers's. Its position is anterior and mesial to Gowers's, encroaching some upon the anterior region of the cord. The fibers of this tract are supposed to come from cells in Deiters' nucleus of the medulla which may be regarded as an internode between the cerebellum and the medulla. This tract descends as far as the lumbar region and its fibers are supposed to arborize around the motor cells of the anterior horn of the spinal cord.

5. The *mixed lateral bundle* represents the remainder of the lateral region. Its fibers probably come from cells in all parts of the gray matter of the cord, and from cells on the opposite side of the cord. At intervals these fibers ultimately reenter the gray matter and arborize about nerve cells. It is therefore an intersegmental or commissural tract, both sensory and motor.

ANTERIOR REGION.

1. *Direct Pyramidal Tract.*—This is a small well-defined tract that lies next to the antero-median fissure. As a rule this tract can only be traced down to the middle of the dorsal region. These fibers originate jointly with those of the crossed pyramidal tract; that is, from the large pyramidal cells of the cerebral cortex. The fibers, however, do not cross in the medulla but pass directly down the cord on the same side. The fibers cross in the cord at intervals in its course, making use of the *anterior commissure* to reach the opposite side, where they arborize around the cells of the anterior horn in a manner like those of the crossed pyramidal. It thus follows that the motor cells on one side of the cerebrum control the muscular contraction on the opposite side of the body, either through the crossed or the direct pyramidal tract or through both.

2. The *anterior ground bundle* is really a part of the mixed lateral tract already described. It is composed of ascending and descending fibers that have both their origin and their termination in the gray matter of the cord and is therefore an intersegmental or commissural tract.

3. *Anterior White Commissure.*—This is composed of medullated nerve fibers passing parallel to the gray commissure between the latter and the bottom of the anterior fissure. It is a decussation of fibers of a mixed variety, many of them being derived from the direct pyramidal tract as already stated.

CHAPTER XIII.

THE BRAIN.

The *brain*, or *encephalon*, develops jointly with the spinal cord, and represents the anterior extremity of the cerebrospinal axis. The average weight of the brain is about forty-eight ounces, while the cord weighs less than one ounce. Like the cord it is an organ in which all the elementary tissues may be found but in which the neurons predominate. During embryonic growth the brain and cord are a hollow tube and this cavity is never obliterated, but remains in the brain as its ventricles. Developmental history further discloses the fact that the brain, like the cord, is made up of definite segments or joints called *neuromeres*. These primary units are soon replaced by three larger vesicles called primary fore-brain, mid-brain, and hind-brain. It is generally affirmed that the first of these represents 3 neuromeres, the second 2 neuromeres, and the third 6 neuromeres. Later the primary fore-brain divides to form the cerebrum and the 'tween-brain, while the hind-brain also divides to form the cerebellum and medulla. In the adult brain, therefore, five divisions may be recognized, each of them presenting a central canal or cavity as designated in the table below:

Primary Divisions.	*Secondary Divisions.*	*Cavity.*
Fore-brain or prosencephalon	1. Telencephalon or cerebrum.	Lateral ventricle.
	2. Thalamencephalon, or diencephalon, or 'tween-brain.	Third ventricle.
Mid-brain.	3. Mesencephalon or mid-brain.	Aqueduct of Sylvius.
Hind-brain or rhombencephalon	4. Metencephalon or cerebellum.	Upper part of fourth ventricle.
	5. Myelencephalon or medulla.	Fourth ventricle.

The brain is thus a hollow multiple organ. Its central cavity is lined with a serous membrane, the ependyma, which secretes a serous fluid, the cerebrospinal fluid. The outer vascular investments are the meninges, which serve as a delicate packing between the brain wall and the bony vault of the cranium.

The Meninges.—These are three connective-tissue investments to the brain that are practically identical and continuous with those already described inclosing the cord. It will be sufficient, therefore, to mention the points wherein these membranes slightly differ.

The *dura* of the brain forms the periosteum of the investing bones, while each segment of the vertebral column has its own periosteum. Several broad prolongations of the brain dura extend between the different divisions of the brain. These are the *tentorium* between the cerebrum and the cerebellum; the *falx cerebri* which dips into the great fissure between the two lobes of the cerebrum, and the *falx cerebelli*, which is a small median septum between the cerebellar hemispheres. At the basal skull foramina, the dura accompanies the cranial nerves and is continuous with the areolar sheaths of these nerves.

The *pia* is composed mostly of areolar tissue and

small blood-vessels. It is the nourishing tissue of the brain and clothes its entire surface, dipping down to the bottom of fissures, and sending strands, associated with blood-vessels, into the brain substance. The brain pia is more vascular than that of the cord.

The *arachnoid* is a web-like membrane between the dura and the pia, but much nearer the dura. The space beneath the dura is called the *subdural space*, and is small. That between the arachnoid and pia is larger and is called the *subarachnoid space*. The former has a little serous fluid, and the latter is filled with lymph and some cerebrospinal fluid. This fluid reaches the external surface of the brain through a small foramen or pore in the thin roof of the fourth ventricle. Trabeculæ intervene between all these membranes.

THE MEDULLA.

The *medulla* is about one inch in length, and represents the portion of the brain next to the spinal cord. Its lower extremity is at the lower margin of the foramen magnum. From this point it passes upward in nearly a vertical direction to its upper extremity at the lower border of the pons. Being the nerve center for the large cranial nerves, the medulla is the most vital part of the brain, and the best protected. Its lower portion resembles the cord, having the same fissures and grooves. The upper portion is expanded in such a manner as to bring its cavity or fourth ventricle to the dorsal surface. This expanding process has carried the dorsal tracts later-

ally, leaving a very thin roof, consisting of the ependyma and a vascular pia, to cover the ventricle. The lower half of the fourth ventricle is found in the upper half of the medulla, while the upper half of this ventricle extends into the pons region and is overlaid by the cerebellum. The central canal of the cord opens into the lowest point of this ventricle and therefore extends through the lower half of the medulla, but nearer its dorsal surface. The lower

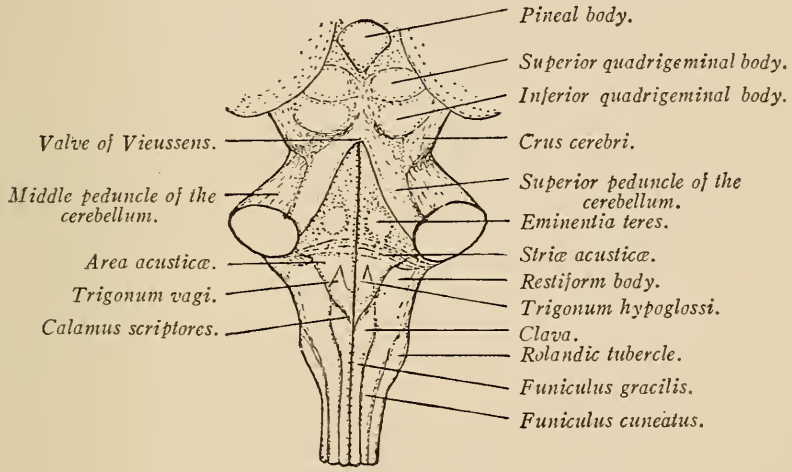


Fig. 269.—Dorsal view of the medulla, pons and mid-brain.

half is therefore spoken of as the *closed medulla* while the upper part, that has the ventricle, is called the *open medulla*.

Two ridges, the *funiculus gracilis* and *funiculus cuneatus*, may be recognized on the dorsal surface of the medulla, and represent the continuation of the columns of Goll and Burdach. The funiculus gracilis terminates anteriorly in a blunt expansion

called the *clava*. On the dorsal aspect of the open medulla is found the *restiform body*, which passes into the *inferior peduncle of the cerebellum* and represents fiber tracts, the most important being the direct cerebellar tract. The lower half of the fourth ventricle is V-shaped and its apex is called the *calamus scriptorius*, from its resemblance to a pen. In its floor three triangular areas are found, called *trigonum vagi*, *trigonum hypoglossi*, and *area acusticæ*. It is in these areas that we find, respectively, the origin of the tenth, twelfth, and eighth cranial nerves. The *striæ acusticæ* are transverse ridges in the floor of this ventricle, extending across its middle part from the median sulcus to

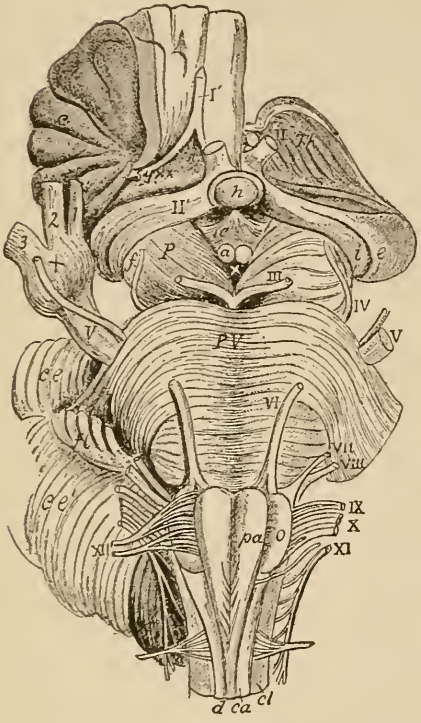


Fig. 270.—View, from below, of the connection of the principal nerves with the brain: I′, the right olfactory tract; II, the left optic nerve; II′, the right optic tract (the left tract is seen passing back into *i* and *e*, the internal and external corpora geniculata); III, the left oculomotor nerve; IV, the trochlear; V, V, the large roots of the trifacial nerves; + +, the lesser roots (the + of the right side is placed on the Gasserian ganglion); 1, the ophthalmic; 2, the superior maxillary; and 3, the inferior maxillary divisions; VI, the left abducens nerve; VII, VIII, the facial and auditory nerves; IX–XI, the glossopharyngeal, pneumogastric, and spinal accessory nerves; XII, the right hypoglossal nerve; C_1, the left suboccipital or first cervical nerve (Nancrede).

the lateral margins, and represent nerve fibers carrying impulses from the eighth cranial nerve.

On the lateral surface of the medulla a prominent oval elevation appears called the *olivary body*, which represents a crescent collection of nerve cells. Just dorsal to the olivary body is the continuation of the dorsal groove of the cord, and it is from this groove that fibers of the ninth, tenth, and eleventh cranial nerves emerge. Near the anterior extremity, at the lower margin of the pons, is the superficial origin of the seventh and eighth nerves. The origin of these nerves corresponds to the entrance into the cord of the posterior root of the spinal nerves. Just median or ventral to the olive is a groove that corresponds to the points of exit of the anterior root of the spinal nerves. From this groove the fibers of the twelfth cranial nerve escape.

The ventral region of the medulla presents a median fissure, the continuation of the anterior fissure of the cord. The upper end of this fissure forms a pit at the lower margin of the pons, called the *foramen cecum*. Just lateral to this cecum, and curving around the pons, is the superficial origin of the sixth pair of cranial nerves. On each side of the median fissure is a longitudinal ridge called the pyramids which represents the fibers of both the crossed and the direct pyramidal tract. Near the lower extremity of the medulla the fissure seems partly obliterated by ridges recrossing. These represent pyramidal fibers crossing to form the crossed pyramidal tract, and constitute, therefore, the *motor decussation*. Just below the olive curved striæ may

be seen, that appear to come from the median fissure and sweep around the olive and enter the cerebellum through the restiform body and inferior peduncle. These are called the *superficial arcuate fibers*, and many of them come from the nerve cells of the olive of both the same and the opposite sides.

Sections of the Medulla.—*Cross Sections of the Closed Medulla.*—These verify the surface markings

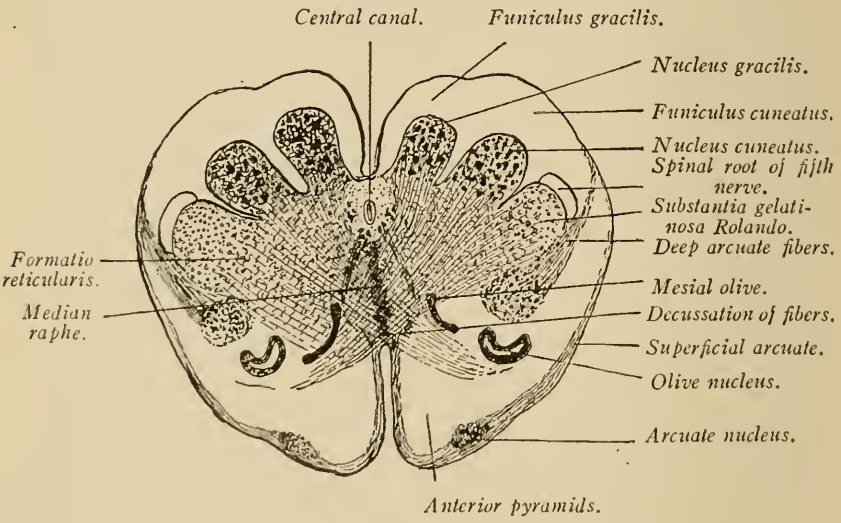


Fig. 271.—Cross section of the closed medulla.

already described. In the dorsal region is the *funiculi gracilis* and *cuneatus*, fiber tracts of the columns of Goll and Burdach. Beneath these are the nuclei of *gracilis* and *cuneatus*, nerve cells around which arborize the telodendria of the fibers of the columns of Goll and Burdach. From these nerve cells axones spring that sweep downward and across to the opposite side, and in crossing form the *sensory decussa-*

tion. It thus happens that the sensory impulses also cross and reach the opposite side of the brain. External to the nucleus gracilis is the *substantia gelatinosa of Rolando*, a continuation of that of the cord. Just external to this is a cross section of nerve fibers, the ascending root of the fifth nerve. The central area of each half of the section shows a large number of scattered nerve fibers interlacing and in cross sections. This area is called the *formatio reticularis.* Anterior to it, a collection of nerve cells represents the olivary body, median and dorsal to which a second and smaller collection of cells constitute the *mesial olivary nucleus.* The bulk of the anterior portion shows a cross section of the *pyramids.* Some of these fibers may be seen to sweep to the opposite side, thus making the *motor decussation.* In doing so they seem to pass over in large alternate bundles, rather than uniformly, as is the case with the sensory decussation. At the anterior surface on each side of the median fissure and sweeping around the pyramids are the *superficial arcuate fibers*, and also a collection of nerve cells, the *arcuate nucleus.*

In *cross sections of the open medulla* the resemblance to that of the cord is less distinct. The thin roof of the fourth ventricle is usually broken, leaving a dorsal expanded cleft. The lateral margin or remnant of the roof is called the *lingula.* Just beneath the floor and close to the median sulcus are the nerve cells of the twelfth nerve. Lateral but in close proximity to these are the nerve cells of the tenth nerve. The axones from these cells may be

traced through the substance of the medulla to their ventral exit. The superficial origin of the twelfth nerve is just anterior to the olive, and the fibers of the tenth nerve may be traced to their superficial origin just dorsal to the olive. In serial cross sec-

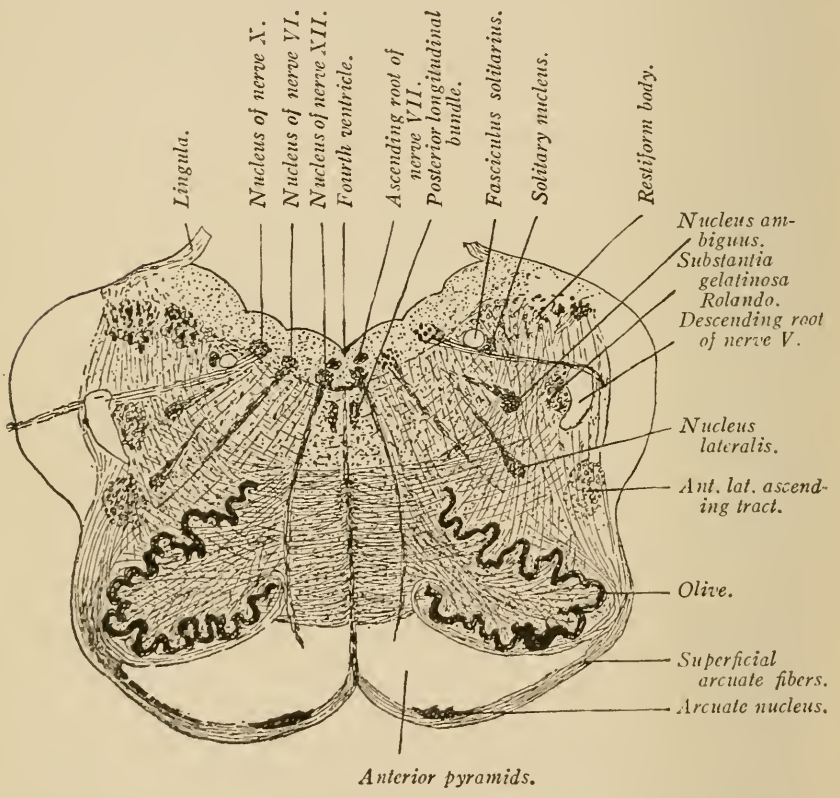


Fig. 272.—Cross section of the open medulla (composite drawing).

tions it will be seen that the nuclei of the other cranial nerves, from the sixth to the twelfth, lie in the floor of the fourth ventricle.

The *fasciculus solitarius* is a bundle of nerve fibers, cut in cross section, and placed just lateral to the

nucleus of the tenth nerve. This bundle represents fibers from the ninth and tenth nerves. Just internal or mesial to this bundle are a few cells called the *solitary nucleus.* This is probably a motor nucleus of the ninth and tenth nerves. Lateral to the solitary fasciculus are the fibers of the large restiform body on their way to the cerebellum.

The *posterior longitudinal* bundle is a tract of nerve fibers that appears in cross section just anterior to the nucleus of the twelfth nerve, and lies in close apposition to the median plane. The formatio reticularis occupies the greater part of the center of each lateral half of the medulla, and presents the same appeareance as in sections of the closed medulla. Likewise the cells of the olivary body, which in the open medulla form a large conspicuous nucleus that takes the form of a U with wavy sides, and with the open extremity turned inward and upward. Nerve fibers from its hilum sweep across to the opposite side and some curve around to join the superficial arcuate fibers of the same side.

The *arcuate fibers* are divided into the *deep* and the *superficial set.* The *deep set* come from the nuclei cuneatus and gracilis and from the sensory nuclei of the cranial nerves. From this source they arch to the opposite side and then turn to pass upward in the brain stem, where they form the *middle fillet.* The superficial set may be divided into an *anterior* and a *posterior* group. The *anterior* group originate in the nuclei gracilis and cuneatus, accompany the deep set to the opposite side of the medulla, where some of them become superficial in the anterior mesial fissure, then curve around the anterior pyra-

mid in the superficial border of the medulla, and finally enter the restiform body and the cerebellum through the inferior cerebellar peduncle. Others become superficial in the antero-lateral groove lateral to the anterior pyramid, passing also to the cerebellum, through the inferior cerebellar peduncle.

The *posterior* group originate in the nuclei gracilis and cuneatus and pass directly forward and upward in the cerebellar peduncle of the same side to terminate in the cerebellum. All the arcuate fibers carry sensory impulses.

The *arcuate nucleus* is a collection of nerve cells interposed in the anterior superficial arcuate fibers at a point just anterior to the pyramids of the medulla.

SUMMARY OF TRACTS, THEIR ORIGIN AND TERMINATIONS.

Columns.	*Origin of Axones.*	*Terminations.*
1. Column of Goll	1. Cells of dorsal ganglion. 2. Cells of posterior horn.	1. Nucleus gracilis.
2. Column of Burdach	1. Same as column of Goll.	1. Nucleus cuneatus.
3. Comma tract	1. Dorsal ganglion	1. Cells of post. horn.
4. Lissaur's tract	1. Dorsal ganglion	1. Cells of post. horn.
5. Direct cerebellar	1. Cells of col. of Clarke	1. Cerebellum.
6. Gowers's tract	1. Cells of post. horn	1. Cerebellum. 2. Corp. quadrigemina. 3. Thalamus. 4. Substantia nigra. 5. Lenticular nucleus.
7. Lowenthal	1. Deiters' nucleus	1. Cells of ant. horn.
8. Lateral ground bundle.	1. Cells of cord	1. Cells of cord.
9. Crossed pyramidal	1. Cerebral cortex	1. Cells of ant. horn.
10. Direct pyramidal	1. Cerebral cortex	1. Cells of ant. horn.
11. Ant. ground bundle	1. Cells of cord	1. Cells of cord.

The sensory tracts are Nos. 1, 2, 3, 4, 5, 6. The motor tracts are Nos. 7, 9, 10. The mixed tracts are Nos. 8, 11.

THE PONS.

The *pons* represents the anterior basal portion of the hind-brain. It is an oval body, one inch long, one inch thick, and about one and one-half inches broad. It is a junctional piece between the medulla

and the mid-brain and the overlying cerebellum. The upper half of the fourth ventricle is confined to its dorsal aspect; that is, between the pons and the cerebellum. Viewed from the ventral surface it presents the appearance of a rhomboid with striations that pass transversely and become constricted laterally to form the middle peduncles of the cerebellum.

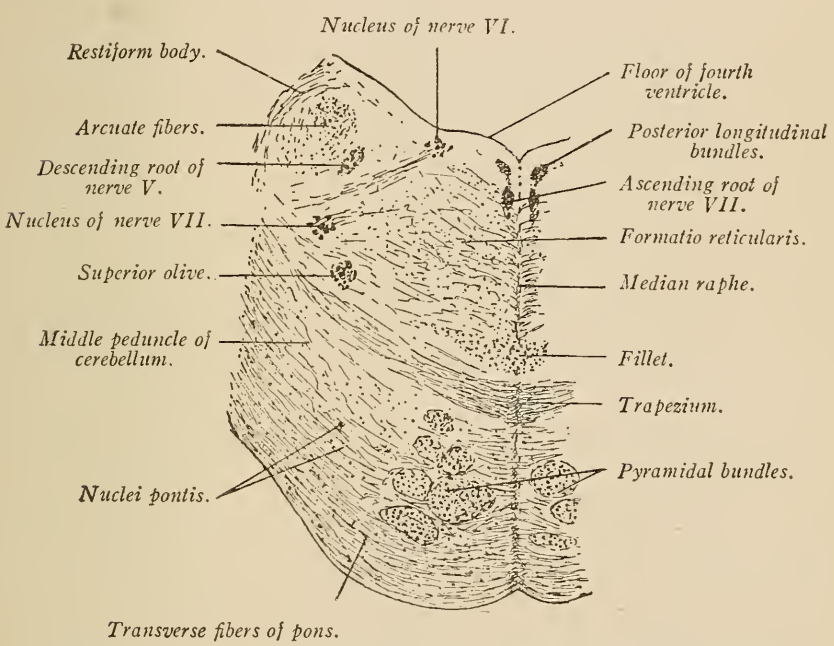


Fig. 273.—Cross section through the lower part of the pons.

The fifth cranial nerve, with its large sensory root and its small motor root, is attached to the ventral aspect of the pons, nearer its upper than its lower border. The anterior pyramids seem to enter the pons from below, and emerge above the pons, where they become lost in the *crura cerebri*.

In a transverse section the pons presents the following parts:

I. White matter.
   1. Transverse fibers—(*a*) superficial, (*b*) deep (trapezium).
   2. Longitudinal fibers—(*a*) superficial (anterior pyramids), (*b*) deep.
   3. Posterior longitudinal bundle.
   4. Fibers of fifth, sixth, seventh, and eighth cranial nerves.
   5. Formatio reticularis.
   6. Median raphe.
   7. Fillet—mesial and lateral.

II. Gray matter.
   1. Nucleus pontis.
   2. Superior olive.
   3. Nuclei the origin of fifth, sixth, seventh, and eighth cranial nerves.

Transverse Fibers.—The superficial and the deep-set of transverse fibers of the pons pass into the cerebellum through the middle peduncle. Some of the fibers are commissural between the two halves of the cerebellum, while others connect with the nuclei pontis on the same side or the opposite side. In the lower portion of the pons, near the medulla, the deep-set are called the *trapezium*, on account of their trapezoid arrangement.

Longitudinal Fibers.—The superficial set represents mostly longitudinal bundles of the anterior pyramids that interlace the transverse fibers. The deep-set are near the dorsal aspect of the pons and comprise at least three groups: (1) the *posterior longitudinal bundle* near the median raphe in which

are found fibers from the antero-lateral column of the cord; (2) the *lemniscus* or *fillet*, a continuation of the sensory decussation; (3) the *fasciculus teres*, just dorsal to the posterior longitudinal bundle, and which contain fibers of the seventh cranial nerve.

Fibers of the cranial nerves pass through the medulla from their nuclei in the dorsal portion to their various superficial exits on the ventral surface.

The *formatio reticularis* is similar to that described in the medulla. The *median raphe* is also a continuation of that described in the medulla.

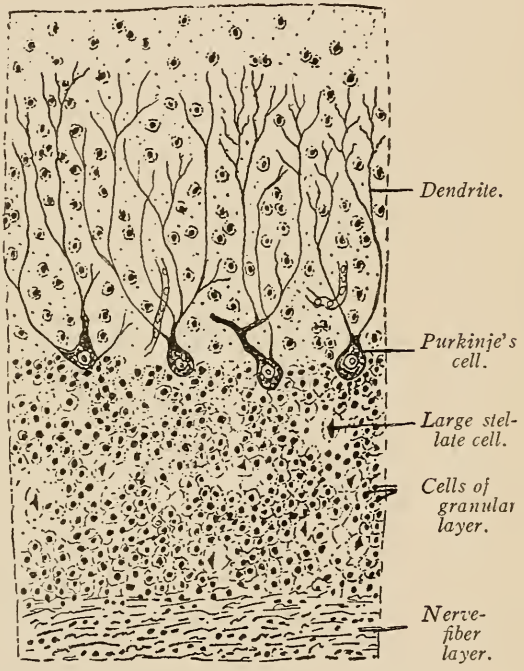


Fig. 274.—Section through the human cerebellar cortex vertical to the surface of the convolution. Treatment with Müller's fluid (Böhm and Davidoff).

Gray Matter of the Pons.—The *nuclei pontis* are nerve cells that are scattered among the superficial transverse fibers and are nodal points forming connections between the medulla, cerebellum, and higher brain centers. The *superior olive* lies in the formatio reticularis and is seen only in the lower portions of the pons. The *nuclei* of the *cranial nerves* are found in the dorsal aspect, most of them just beneath the floor of the fourth ventricle.

THE CEREBELLUM.

The *cerebellum* is next in size to the cerebrum and overlies the fourth ventricle. It is characterized by transverse curved sulci which divide it into lamellæ, giving the organ a foliate appearance. A cross section of the lamellæ shows a central core of white matter with a gray cortex, giving the section the appearance of a branching tree, hence the name *arbor vitæ*. A section taken in this plane presents the following layers:

1. Molecular layer—on the outside.
    (1) Small cortical cells.
    (2) Stellate cells.
    (3) Cells of Purkinje.
2. Granular layer.
    (1) Granular cells.
    (2) Large stellate cells.
3. Medullary substance—core of nerve fibers.
    (1) Centrifugal neuraxes from Purkinje cells.
    (2) Centripetal neuraxes.
        (*a*) Mossy fibers.
        (*b*) Climbing fibers.
    (3) A few ganglion cells forming the central gray nucleus.

Molecular Layer.—The *small cortical cells* are found in all parts of this layer, but more especially near its periphery. They are multipolar cells and but little is known of the distribution of their neuraxes. The *stellate cells* are evenly distributed, and of particular interest are their *neuraxes*. The latter possess two types of collaterals. One set forms branches among the cortical cells, while a second class branches

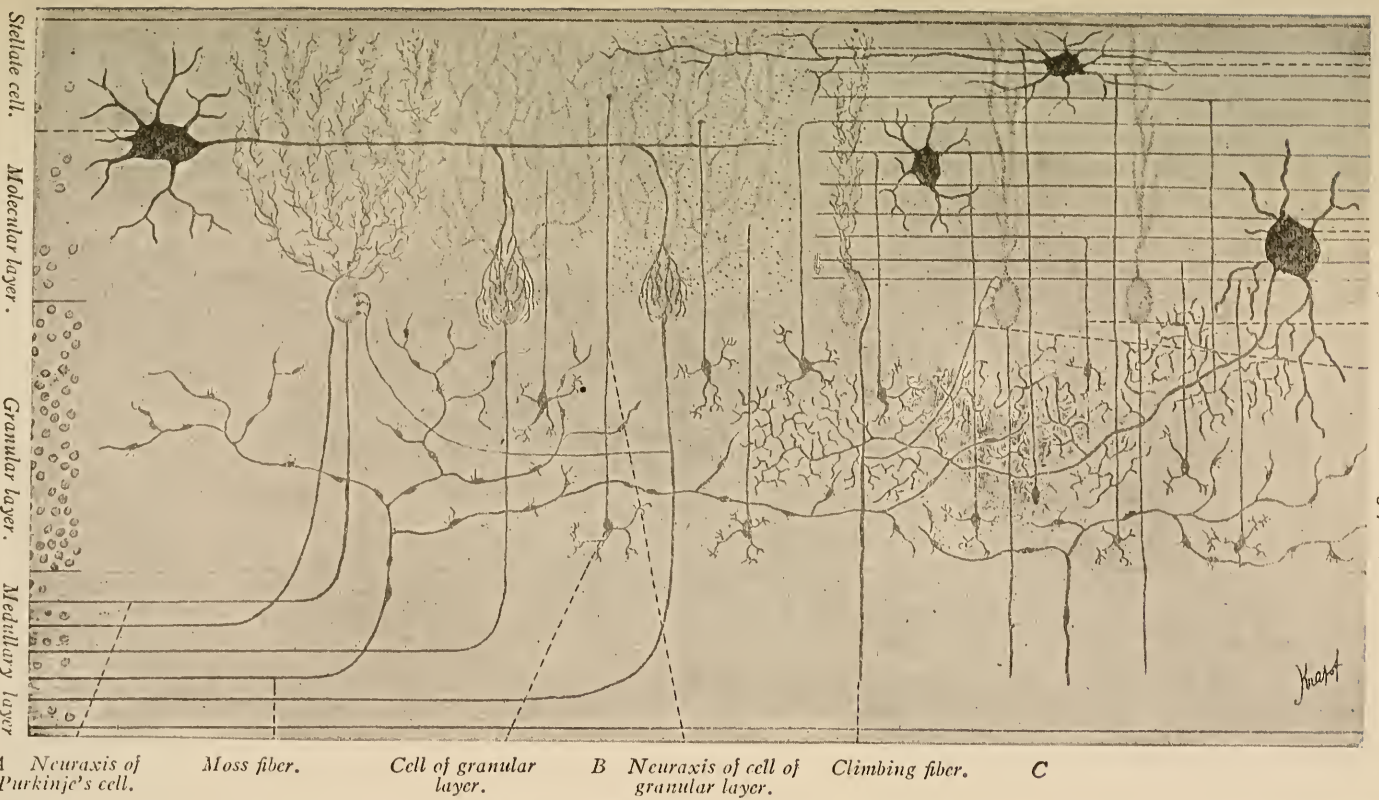


Fig. 275.—Schematic diagram of the cerebellar cortex: *A*, by ordinary nuclear staining (omitting the layer of Purkinje's cells); *B*, vertical to the surface of the convolution; *C*, longitudinal section through the convolution; *B* and *C*, by the chrome-silver method (Böhm and Davidoff).

at a level with the Purkinje cells, where it forms a basket-like net around the bodies of these cells. The *cells of Purkinje* are the largest nerve cells in the body (about 60μ in diameter or seven times the diameter of a red blood-corpuscle). They form a single row of cells, placed with considerable regularity some distance apart, along the inner margin of the molecular layer. Their neuraxes arise from the basal end of the cell body and extend through the granular layer and enter the medulla as the centripetal fibers. The other extremity of the cell body passes into one or more prominent dendrites that arise toward the

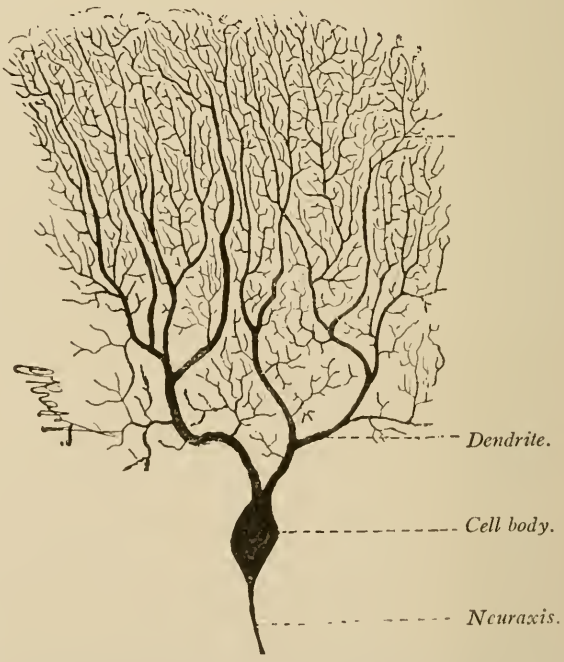


Fig. 276.—Cell of Purkinje from the human cerebellar cortex. Chrome-silver method (Böhm and Davidoff).

periphery of the cerebellum. These dendrites branch freely in one plane, like an ivy growing against the wall, and this plane is always at right

angles to the lamellæ of the cerebellum, and therefore sections of the cerebellum should be made in this plane.

Granular Layer.—This layer is densely packed with nerve cells of two varieties. The *granular cells* are most numerous, small, and have only a few dendrites that end in hook-like telodendria. The neuraxes from these cells pass vertically into the molecular layer, where many of them form a T-shaped division, the two end branches passing parallel with the laminæ and therefore into a plane vertical to that of the dendrites of the Purkinje cells. *Large stellate cells* form the second variety of this layer. They are few in number and lie close to the molecular. Their dendrites branch in all directions and their neuraxes form telodendria among the granular cells.

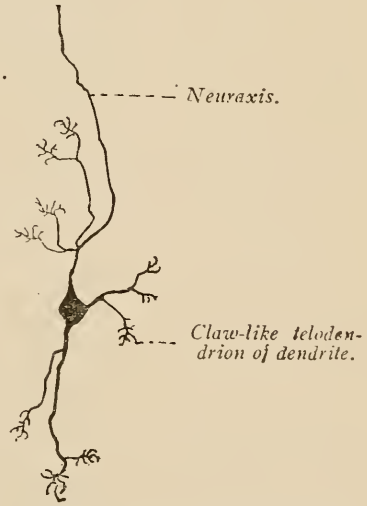


Fig. 277.—Granular cell from the granular layer of the human cerebellar cortex. Chrome-silver method (Böhm and Davidoff).

The medullary substance may be divided into *centripetal fibers*,—those that carry nerve impulses toward the granular and molecular layers, and *centrifugal fibers;* those that carry impulses in the opposite direction. The latter are the neuraxes of the cells of Purkinje. The centripetal fibers are the *mossy fibers*, that form mossy telodendria in the granular layer, and also so-called *climbing fibers* that pass through the granular

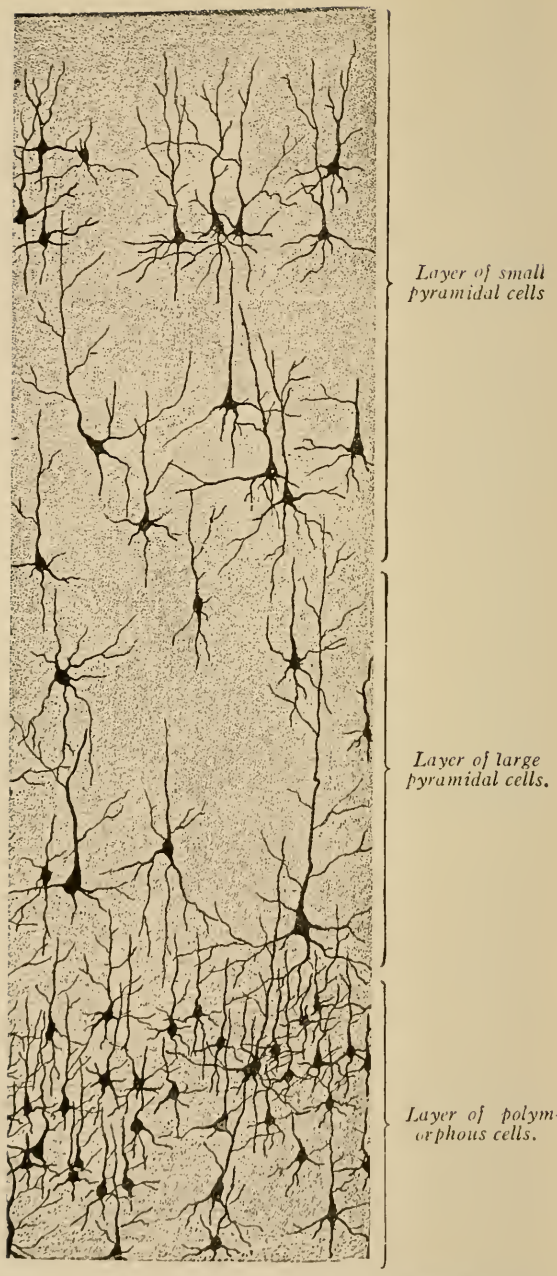


Fig. 278.—Portions of vertical section of human cerebral cortex, treated by the Golgi method. The figure shows the arrangement of the different cells of the cerebral cortex (Sobotta).

layer and connect with the dendrites of Purkinje cells, up which they seem to climb. Collaterals are given off in their passage through the granular layer. The *central gray* nucleus forms the central core of each lateral cerebellar hemisphere. It forms a capsule of gray matter from whose hilum many nerve fibers pass, the majority to enter the superior cerebellar peduncle.

THE CEREBRAL CORTEX.

The *cerebrum* is such an extensive and complicated organ that only a description of the cortex in the region of the fissure of Rolando will be given here. From without inward this region presents, rather indistinctly, the following layers: (1) molecular layer; (2) small pyramidal cells; (3) large pyramidal cells; (4) polymorphic cells; (5) medullary substance of nerve fibers. It is to be borne in mind that this cortex presents many fissures and minor folds into which the pia dips, and that a transverse section is any plane that is vertical to the folded surface.

1. The *molecular* or *outer layer* is composed chiefly of nerve fibers which interlace in all directions but which have chiefly a direction parallel to the external surface. The chief dendrite of the pyramidal cells terminates in this layer in tuft-like telodendria, and also ascending neuraxes, mostly from the polymorphous cells. The cells of this layer are few, and have been described as polygonal, spindle-shaped, and triangular, or stellate. Their neurons are nearly all confined to this layer, the axones of only a few reach down to the deeper layers.

2. The layer of *small pyramidal cells* is not well defined and usually not so broad as the molecular layer. The nerve cells have a triangular body, the apex being directed toward the surface of the cortex. From this apex a primordial dendrite ascends and

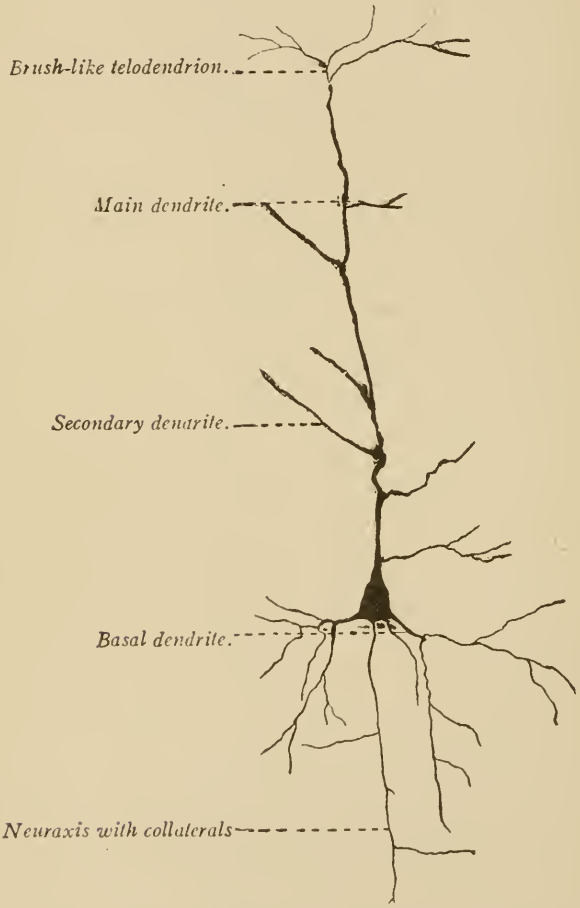


Fig. 279.—Large pyramidal cells from the human cerebral cortex. Chrome-silver method (Böhm and Davidoff).

gives off a number of branches that end in terminal filaments or telodendria in the outer layer, frequently at the brain surface. Several short dendrites arise

from the basal surface of the cell body where also the axone is attached. The latter passes toward the medullary substance, and near the cell body is provided with collaterals that connect with adjacent neurons.

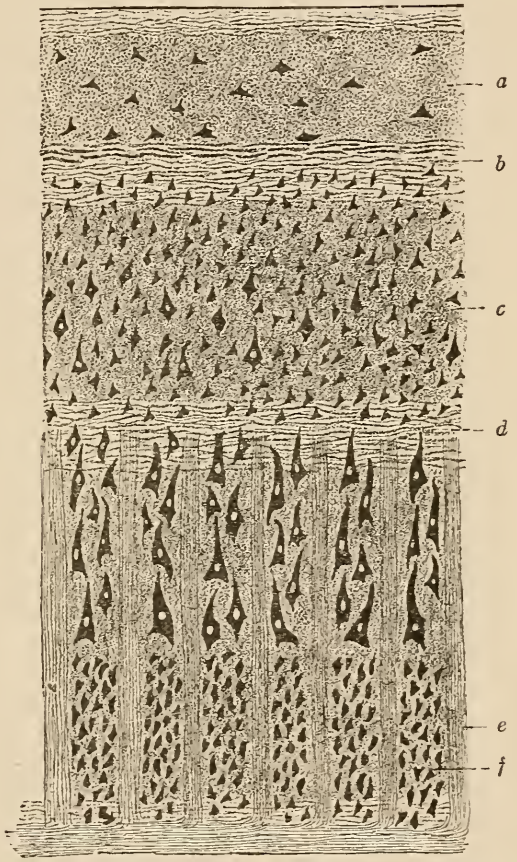


Fig. 280.—Schematic diagram of the cerebral cortex: *a*, Molecular layer with superficial (tangential) fibers; *b*, striation of Bechtereff-Kaes; *c*, layer of small pyramidal cells; *d*, stripe of Baillarger; *e*, radial bundles of the medullary substance; *f*, layer of polymorphous cells (Böhm and Davidoff).

The layer of *large pyramidal cells* comprises a broad area. The cells measure 20 μ to 30 μ in diameter, being twice as large as those of the preceding layer. In all other respects the cells of this layer resemble the small pyramidal cells. Their dendrites and axones also occupy the same relation as those of the preceding layer.

4. The layer of polymorphic cells usually includes

a few large pyramidal cells, and it is not well defined from the preceding layer. There is present in this layer: (1) multipolar cells with short neuraxes (Golgi cells) whose dendrites project in all directions; and (2) cells with slightly branched dendrites and with neuraxes passing toward the surface of the brain where they terminate in the molecular outer layer. The cells of this layer are triangular or spindle-shaped and vary considerably in size.

5. The *medullary substance* is composed of a mass of nerve fibers that take a radial course and in which we can detect no structural difference. Physiologically, however, we can divide them into four classes as follows: 1, projecting or centrifugal fibers which indirectly connect the cerebral elements with the periphery of the body; that is, they carry impulses away from the nerve center; 2, commissural fibers that connect corresponding parts of the two cerebral hemispheres through the corpus callosum; 3, association fibers that connect different parts of the same hemisphere; 4, centripetal fibers or terminal fibers,—those that come from cell bodies in the same or the opposite hemisphere, or in some more distant nerve center, and that ultimately arborize about nerve elements in the cerebral cortex. In a strict sense the second and the third class fall under either the centrifugal or the centripetal group.

THE NEUROGLIA.

The neuroglia tissue represents a special form of supporting elements found exclusively in the central nervous system and in the retina. It develops from

the ectoderm while all other supporting tissues are derived from the mesoderm. The development of neuroglia cells is closely associated with the origin of neurons, as both are derived from epithelial cells that lie primarily near the central canal of the nervous system. The embryonic neuroglia cells are called spongioblasts, while those that develop into true nerve elements are called neuroblasts. Both kinds pass out very early and permanently lodge in the gray matter.

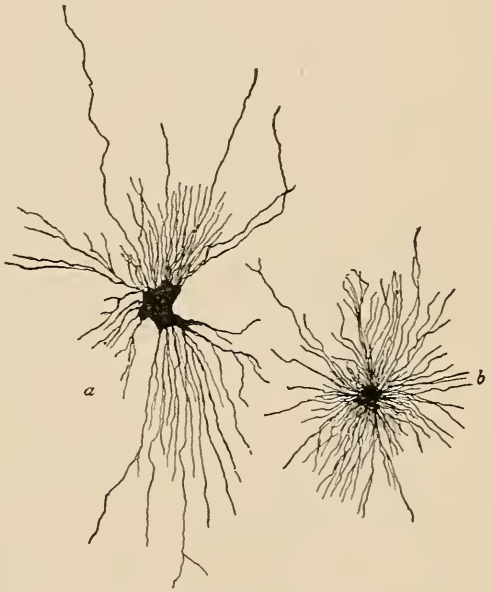


Fig. 281.—Neurogliar cells: *a*, from spinal cord of embryo cat; *b*, from brain of adult cat; stained in chrome-silver (Huber).

The neuroglia elements appear as cells with many radiating, slender processes that are usually unbranched, and because of their peculiar appearance have been called *spider cells* or *mossy cells*, or *astrocytes*. The cell bodies contain but very little protoplasm, and their shape is modified according to their surroundings, being triangular, or quadrangular, or polyangular, the protoplasmic processes arising from their angles. According to the length of their processes attempts have been made to classify them as short-rayed astrocytes, pos-

sessing a few short processes, and long-rayed astrocytes, having many long, slender processes. The former appear among the nerve cells only, the latter are found both in the gray and the white matter.

Fig. 282.—Typical neuroglia cells, from cross section of the white matter of the human spinal cord, stained after Benda's selective neuroglia tissue staining method (Huber, "Studies on Neuroglia Tissue," *Vaughan Festschrift*, 1903).

Not infrequently detached processes may be found and processes that can be traced directly through the bodies of adjacent astrocytes. The neuroglia thus forms a delicate web-like fabric that interlaces

the whole central nervous system, to which it gives substance and support. It is to be remembered that supporting tissue of mesodermic origin does the same thing, especially in the cord. The connective-tissue elements usually accompany the nutrient blood-vessels.

BLOOD-VESSELS OF THE CENTRAL NERVOUS SYSTEM.

The spinal cord receives its blood supply from a plexus of blood-vessels in the pia mater. There is an anterior median artery just in front of the anterior fissure. Some two hundred branches from this vessel pass at right angles directly into the fissure and enter the gray matter, where each divides into a right and left branch that enclose the central canal. Each arterial branch ultimately bifurcates, just in front and external to the cell column of Clarke, forming minute ascending and descending terminals, which become lost in an extensive capillary system of the central gray matter. The white matter receives its blood supply from a plexus of vessels situated on the dorsal and lateral surfaces of the cord. From this system small branches enter the cord anywhere and form capillaries among the nerve fibres; that is, supplies blood to the white matter. The gray matter has a more liberal blood supply than the white matter.

The brain substance also receives its blood supply from a plexus of blood-vessels in its pia. The capillaries are particularly numerous and closely meshed wherever the nerve cells are segregated, that is, in the ganglion centers. In the cerebellum the gran-

ular layer is the most vascular. The arterioles have thin walls, and in old age may become brittle and may easily rupture.

No lymphatic vessels with definite walls have been discovered in the central nervous system. The blood-vessels are, however, surrounded by perivascular spaces which probably function as lymph channels.

CHAPTER XIV.

THE EYE.

The *eyes* begin to develop during the fourth week of embryonic life, and appear then as a pair of lateral evaginations of the fore-brain. A pair of vesicles are thus formed called the *primary optic vesicles*. When the latter reach the ectoderm an invagination of these vesicles takes place, like pushing in one side of a hollow rubber ball. The cavity of the primary optic vesicle becomes obliterated by this process, and a new vesicle forms, called the *secondary optic vesicle*. It will be observed that the cavity of this vesicle is practically the same as would be produced by an invagination of the brain wall. Later it will be seen that this cavity corresponds to the space occupied by the vitreous humor of the adult eye, while its wall becomes the retina. The stalk that connects this vesicle to the brain is the optic stalk, in which later optic nerve fibers appear.

At the time the secondary optic vesicle is forming there is a disc-like thickening of the adjacent ectoderm, which soon invaginates and becomes constricted as an ectodermal vesicle. This is the *lens*, which later takes a position at the mouth of the secondary optic vesicle. The latter presents, at this stage, a fissure in its ventral surface called the *choroid fissure*. Connective-tissue cells migrate through

this fissure and fill the cavity of the secondary vesicle.

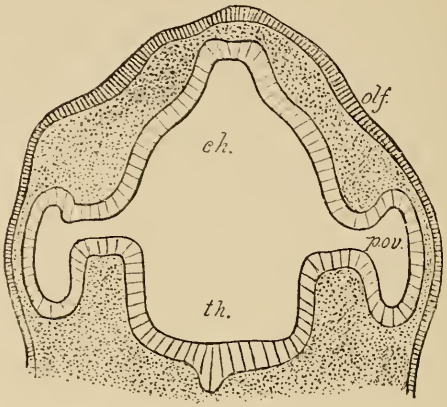


Fig. 283.—Part of a section through the head of an early human embryo, showing the connection of the primary optic vesicles with the fore-brain (His): *olf*, Olfactory area of epiblast; *ch.*, part of fore-brain which gives rise to cerebral hemispheres; *th*, thalamencephalon; *p.o.v.*, primary optic vesicles.

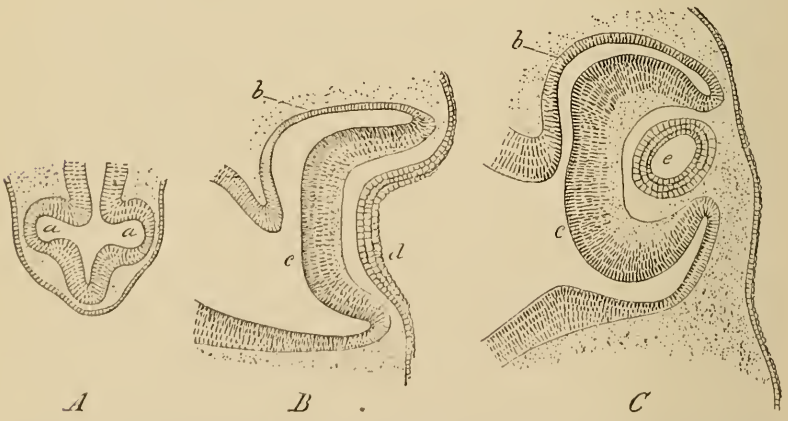


Fig. 284.—Three successive stages of development of the eye, showing formation of secondary optic cup and crystalline lens in human embryos of 4 mm. (*A*), 6 mm. (*B*), and 8 mm. (*C*) (Tourneux): *a*, *a*, primitive optic vesicles; *b*, external layer of secondary optic cup (future pigment layer of retina); *c*, inner layer of cup (retina proper); *d*, lens pit (thickened and depressed ectoderm); *e*, lens vesicle.

These cells form the *vitreous humor*, while the choroid

fissure closes and permanently disappears. The external coats of the eye—that is, the sclera and the choroid—develop from the surrounding connective tissue.

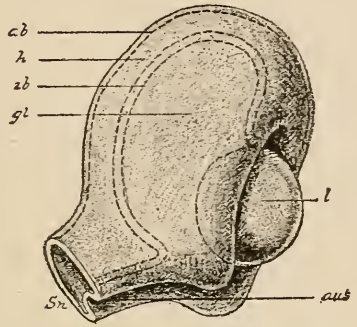


Fig. 285.—Plastic representation of the optic cup with lens and vitreous body (Hertwig): *ab*, Outer wall of the cup; *ib*, its inner wall; *h*, cavity between the two walls, which later disappears entirely; *Sn*, fundament of the optic nerve (stalk of the optic vesicle with a furrow on its lower surface); *aus*, optic (choroid) fissure; *gl*, vitreous body; *l*, lens.

The parts of the adult eyeball may be tabulated as follows:

I. Tunica externa.
   1. Sclera.
   2. Cornea.

II. Tunica media.
   1. Choroid coat.
   2. Ciliary body.
   3. Iris.

III. Tunica Interna.
   1. Retina.
   2. Pigment membrane.

The refracting media, or transparent media of the eye traversed by a ray of light, are:

1. The cornea.

2. Aqueous humor.
3. Lens.
4. Vitreous humor.

TUNICA EXTERNA.

1. The **sclera** is a dense connective-tissue covering of the eye that terminates anteriorly in the cornea. It is of interest to note that, in birds of prey, horny plates develop in the sclera for the better protection

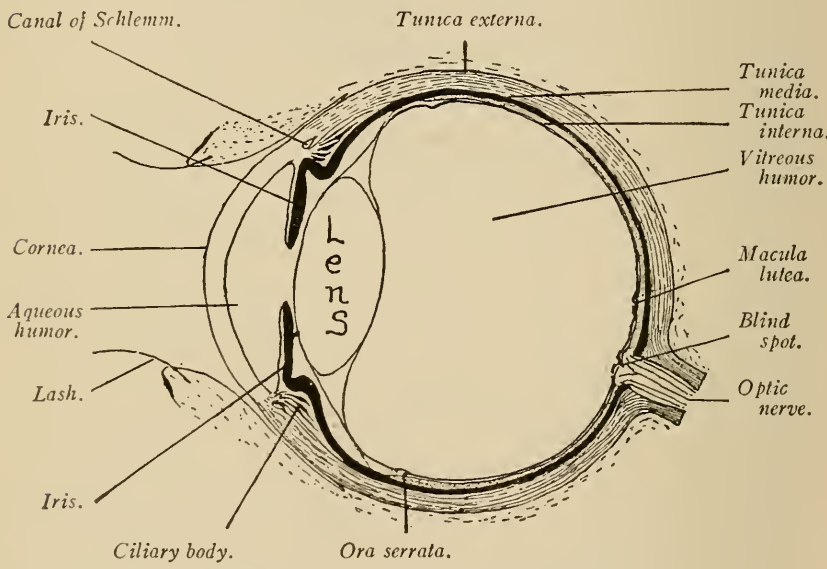


Fig. 286.—Diagram of the eye.

of the eye. Posteriorly the sclera is perforated by the entrance of the optic nerve. Connective-tissue fibers, known as the *lamina cribrosa*, pass across this point and interlace the optic fibers, while others sweep backward along the optic nerve as its external envelope.

The sclera consists of interlacing bundles of con-

nective-tissue fibers closely felted together. The tendons of the ocular muscles are continuous with the scleral fibers. The external scleral surface is clothed with a layer of flattened endothelial cells which belong to the *capsule of Tenon.* The latter is a loose connective-tissue fabric that invests the eyeball, and is so intimately connected with the eye muscles that coordinate movement of the artificial eye, or glass shell, is made possible after the enucleation of an eye. Pigmentation is regularly present at the corneal margin and the surface next to the choroid. This inner pigmented scleral surface is lined by a layer of flattened endothelial cells, forming a separate membrane and called by some the *lamina fusca;* generally, however, it is regarded as the outermost layer of the choroid and known as the *lamina choroidea.*

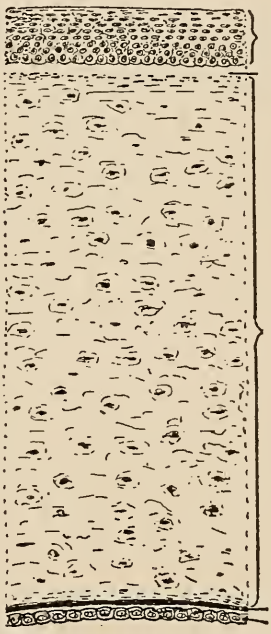


Fig. 287.—Section of the cornea of the eye.

2. **The Cornea.**—The cornea is inserted into the sclerocorneal junction in which is found an annular venous sinus, the *canal of Schlemm,* which may appear as a single canal or as several canals. The cornea is a perfectly transparent medium and free

from red blood corpuscles, the nearest blood supply being that of the sclerocorneal margin in the region of the canal of Schlemm.

Histologically the cornea is made up of five layers: 1, the anterior epithelium; 2, the anterior elastic membrane, or Bowman's membrane; 3, the ground substance, or substantia propria; 4, Descemet's membrane; 5, the endothelium of Descemet's membrane.

The *corneal epithelium* is of the stratified squamous variety, a little thicker near the corneal margin than at its center and in the human eye is composed of five layers of cells. It is related to the epidermis of the skin, the cells being provided with short prickles that are very difficult to demonstrate. This epithelium forms an efficient and important protection to the front of the eye. The *anterior elastic membrane* measures 8 μ in thickness, about the width of a red blood corpuscle, and becomes thinner towards the sclerocorneal junction. It is a compact layer of connective-tissue fibrils and is regarded by some as a basement membrane to the overlying epithelium. Nerve fibers penetrate this membrane to connect with the corneal epithelial cells. The *substantia propria* constitutes the bulk of the cornea. It consists of bundles and lamellæ of connective-tissue fibrils, and peculiarly flattened cells called *corneal corpuscles*. The fibrils of each lamella are cemented together and run parallel to each other and to the corneal surface, but so arranged that those of adjacent lamellæ cross at an angle of about twelve degrees.

The lamellæ are also cemented to each other. The

corneal cells have irregular processes and lie in special cavities called *corneal spaces*, in which are also found a varying number of leucocytes. These spaces seem to be part of a complicated lymphatic system, and communicate with each other by means of a complex system of canals. While blood does not irrigate the cornea, lymph does, freely and extensively. The *posterior elastic* or *Descemet's membrane* resembles the

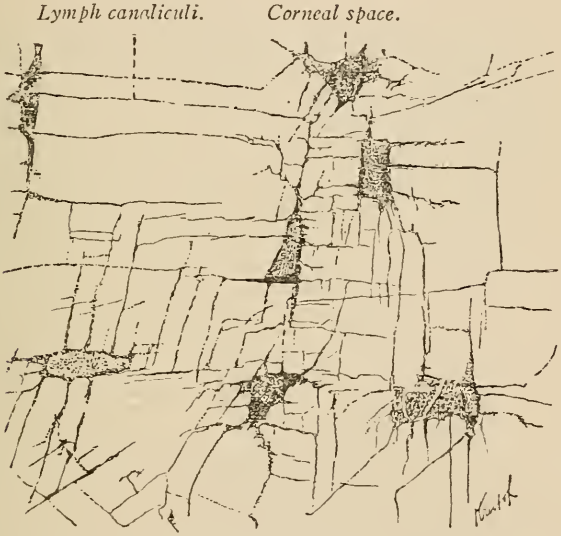


Fig. 288.—Corneal spaces of a dog (Böhm and Davidoff).

anterior elastic membrane, and may be separated into shreds of fine, elastic, connective-tissue fibrils. The *endothelium* of Descemet's membrane is composed of low, hexagonal cells forming a single layer. It will be found that Descemet's membrane with its investing endothelium is reflected to form the anterior layer of the iris, enclosing therefor the anterior portion of the aqueous chamber.

TUNICA MEDIA.

1. **The Choroid Coat.**—The choroid is the vascular tunic of the eye, and may be divided into four layers. From without inward these are named: 1, lamina suprachoroidea; 2, lamina vasculosa Halleri; 3, lamina choriocapillaris; 4, glassy layer, or vitreous membrane. This entire tunic is derived from the

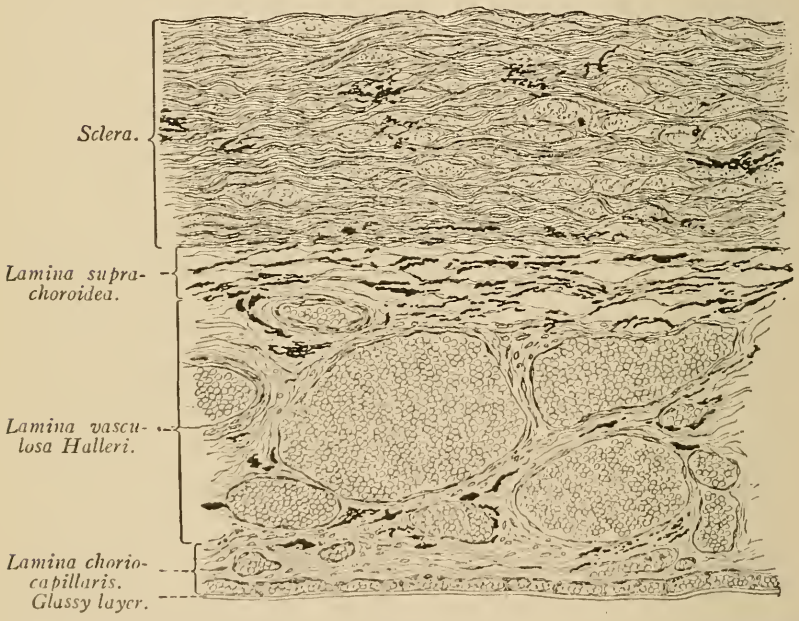


Fig. 289.—Section through the human choroid (Böhm and Davidoff).

mesoderm and is largely composed of connective-tissue elements.

The Lamina Suprachoroidea.—This layer is closely applied to the sclera, and is composed of a loose fabric of areolar tissue in whose meshes are connective-tissue cells and lymph spaces lined with endothelium, known as *perichordeal lymph spaces.*

Pigment cells are also present. The lamina vasculosa is the broadest layer and is also composed of areolar tissue. The blood-vessels constitute its principal portion, and they are so distributed that the larger ones, the veins, occupy its outer portions. The *lamina choriocapillaris* consists chiefly of capil-

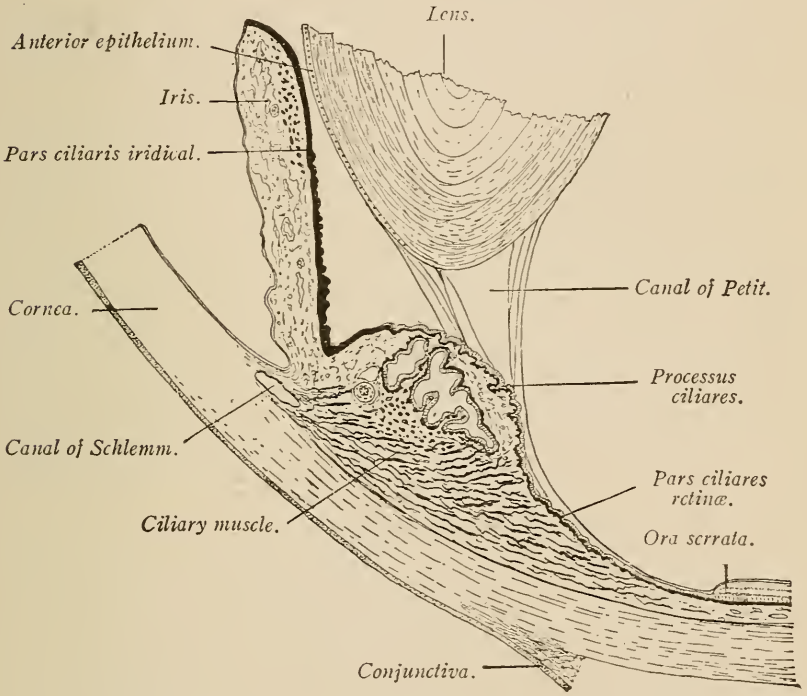


Fig. 290.—Section through the ciliary body.

lary vessels that are particularly abundant in the region of the macula lutea, or yellow spot of the retina. In other respects this layer resembles the lamina suprachoroidea, except that pigment cells are absent. The *glassy* or *vitreous membrane* is but 2 μ thick, homogeneous, clothes the inner choroid

surface, and also forms a lining membrane against which the pigment cells of the retina are applied.

2. **The Ciliary Body.**—The ciliary body is that portion of the tunica media extending between the ora serrata of the retina and the base of the iris. On the inner surface of this body there are about seventy meridional folds called the *ciliary processes*. Secondary folds and processes appear on and between the primary folds, while the whole surface is clothed with two rows of epithelial cells, the *pars ciliaris retinæ*. Of these the outer layer is deeply pigmented and represents the outer layer of the secondary optic vesicle, while the inner layer is non-pigmented and develops from the inner layer of the optic vesicle. The greater bulk of the ciliary body is made up of smooth muscle tissue called the *ciliary muscle*, or *muscle of accommodation*. This muscle may be divided into three portions. The outer portion is made up of meridional fibers. The middle division of radial fibers have their origin near the canal of Schlemm, from which they spread out like a fan. The inner portion is near the base of the iris and the fibers are circular. The combined action of these fibers is to pull the choroid coat forward and inward and thus slacken the tension on the suspensory ligament of the lens, as this ligament joins with the epithelial cells of the ciliary body as well as with the hyaloid membrane that encloses the vitreous humor. Under this condition the lens becomes more convex and the eye is focused to near objects.

3. **The Iris.**—The iris is a pigmented circular curtain that occludes the rays of light from the periphery

of the lens. The circular opening in the iris is the *pupil*. Three layers may be recognized in the iris, enumerated from before backward, as follows: 1 anterior endothelium; 2, stroma with sphincter muscle; 3, pigment epithelium, or pars iridica retinæ. The *anterior endothelium* is a single layer of cells that is continuous with the posterior endothelium of the cornea. The *stroma* forms the bulk of the iris and is very vascular and muscular. Large pigment cells are present and a fine reticular tissue. Smooth muscle fibers, the sphincter muscle of the pupil, encircle the pupil. Along the posterior surface radial fibers probably function as a dilator muscle of the pupil. The *posterior epithelium*, or pars iridica ciliaris, is a direct continuation of the pars ciliaris retinæ and extends to the margin of the pupil. It is composed of two layers of cells and both, in this case, are pigmented.

TUNICA INTERNA.

The *inner tunic* is the retina of the eye, which may be divided into ten layers, named from within outward as follows:

1. Internal limiting membrane.
2. Layer of nerve fibers.
3. Ganglion cell layer.
4. Inner molecular layer.
5. Inner nuclear layer.
6. Outer molecular layer.
7. Outer nuclear layer.
8. External limiting membrane
9. Rods and cones.
10. Pigment layer.

(1) The *internal limiting membrane* is a very delicate homogeneous layer formed by lateral expansions of processes of neuroglia elements. It is closely applied to (2) the *optic nerve fibers*. The latter are nonmedullated and radiate toward the entrance of the optic nerve, composed of both centrifugal and centripetal axones. The latter arise from (3) the *ganglionic cells*, that are irregularly distributed along the inner

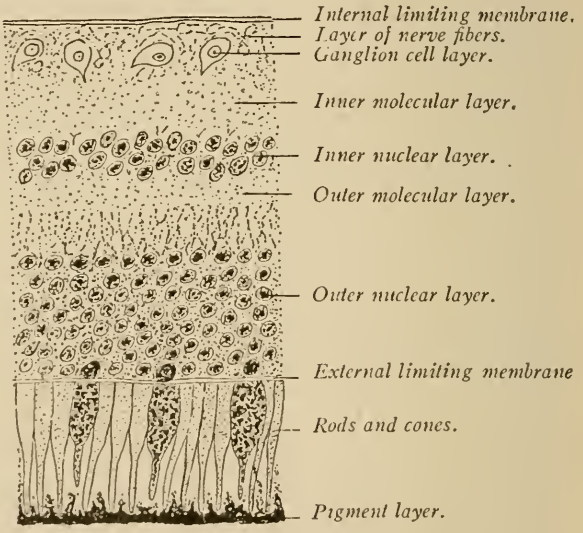


Fig. 291.—Section of retina of the eye.

border of the retina. These cells are large, multipolar, and their dendrites extend outward and contribute to the substance of (4) the *inner molecular layer*. The latter is a network of neuroglia fibrils and nerve processes, contributed in part by the cells of (5) the *inner nuclear layer*. This layer is composed of several rows of nucleated cells of which some are sustentacular, or neuroglia elements, some bipolar ganglion cells, and others multipolar ganglion

cells situated in the outer region of this layer and expanding in a horizontal direction. (6) The *outer molecular layer*, like the inner molecular, is a network of fibrils, processes from all the ganglion cells of the retina and also neuroglia elements. The external portion of this molecular layer is not so densely packed with fibrils and has been called *Henle's fiber layer*. (7) The *outer nuclear layer* is composed of many compact rows of nuclei and is the most conspicuous layer in stained sections of the retina. The cell bodies enclosing most of these nuclei are the visual units of the eye and are called *rod-visual* and *cone-visual* cells, as the rods and cones are merely processes of these cells. The cells are elongated units whose long axis is placed radial to the eye, and whose multiple processes enter the outer molecular layer as already mentioned. The cone-visual cells are least numerous and their nuclei are placed at regular intervals in the outer portion of the layer. Their nuclei are somewhat larger than the nuclei of the other cells. Rod-like neuroglia elements give support to the visual cells. (8) The *external limiting membrane* invests the outer nuclear layer. It is a thin, transparent, homogeneous membrane, derived from the neuroglia tissue, and forming a dividing line between the rods and cones and the outer nuclear layer. (9) The *rods* and *cones* are processes from the visual cells whose nuclei form the bulk of the outer nuclear layer. The *rods* are 40 μ to 50 μ in length, and consist of two segments, the outer being doubly refractive to light, and may be separated into numerous transverse discs by the action of certain reagents.

The inner segment shows a superficial longitudinal striation, due to impressions from fiber baskets of the neuroglia network. The cone is 15 μ to 25 μ long and its inner segment considerably broader than the rod. The rods are more numerous than the cones, three or four of the former intervening between two of the latter. (10) The pigment layer forms a compact background to the rods and cones. It consists of hexagonal cells that contain black pigment granules. The inner surfaces of these cells possess thread-like filaments that interlace between the rods and cones. The nuclei of these cells lie in the outer ends of these cells, the so-called basal plates, and are not pigmented. The granules are mobile and their distribution in the cells varies according to the illumination of the retina. In strong light the pigment is evenly distributed throughout the cytoplasm, while in weak light it is collected at the outer portion of each cell. This single row of pigment cells represents the outer layer of the primary optic vesicle, while the other nine layers of the retina develop from the inner layer of this vesicle.

The *neuroglia elements* of the retina differ from those of the brain in that they form radial sustentacular fibers, called fibers of Müller, which penetrate the retina to the rods and cones. Each fiber represents a modified epithelial cell which terminates in basal plates, the latter forming the limiting membranes of the retina. The end plates that form the external limiting membrane give off externally short, inflexible fibrils, which form *fiber-baskets* enclosing the basilar portions of the rods and cones. The

bodies of Müller's fibers are very plastic and adjust

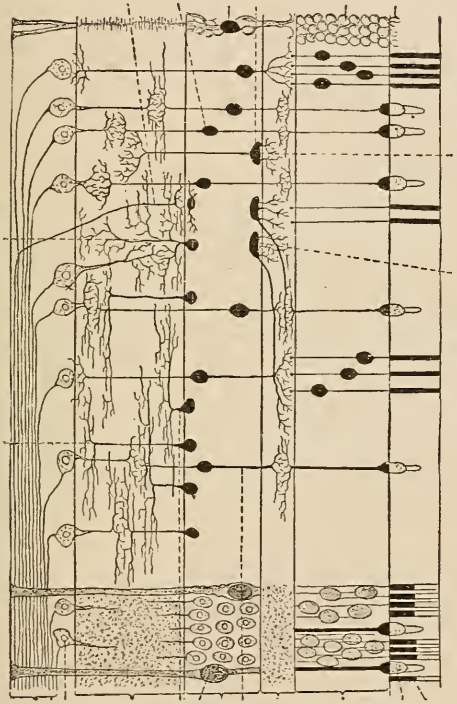


Fig. 292.—Schematic diagram of the retina according to Ramón y Cajal: The line *a*, after passing through a Müller's fiber, crosses a bipolar rod cell, then two bipolar cone cells, and finally ends in the body of a bipolar cone cell (Böhm and Davidoff).

themselves to the pressure exerted by the various

elements that constitute the different layers of the retina through which they pass.

In certain areas of the retina there are peculiarities that differ from the above description. These areas are: (1) the macula lutea, or yellow spot; (2) the optic papilla, or blind spot; (3) the ora serrata; (4) the pars ciliaris retinæ; (5) the pars iridica retinæ.

1. The *macula lutea*, or yellow spot, is a crater-like area of the retina that lies in the visual axis of

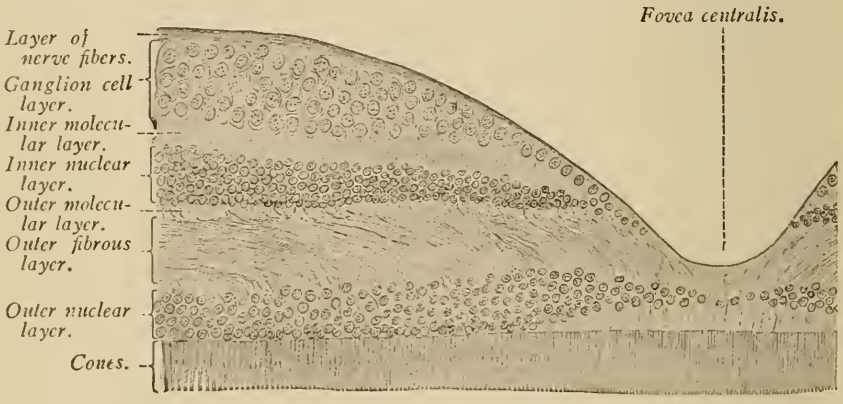


Fig. 293.—Section through human macula lutea and fovea centralis. As a result of treatment with certain reagents, the fovea centralis is deeper and the margin more precipitous than during life (Böhm and Davidoff).

the eye. The central depression is called the *fovea centralis*. Its margin is somewhat thickened and presents all the layers of the retina, while in the fovea the layers are practically reduced to the cone-visual elements. From this center the cell bodies of the cones radiate in curves to reach the outer molecular layer, which gives rise to obliquely directed fibers known as *Henle's fiber layer*. The macula lutea is the most sensitive spot in the retina and derives its

name from the yellow pigment held in solution within the cell layers.

2. The *optic papilla*, or blind spot, is the point of entrance of the optic nerve. It is found a little to the nasal side of the macula lutea. From the center of this papilla the nerve fibers spread out radially to supply the various parts of the retina. The optic fibers lose their medullary sheaths in their passage through the sclera and the choroid, so that the optic nerve at this point becomes suddenly thinner. Be-

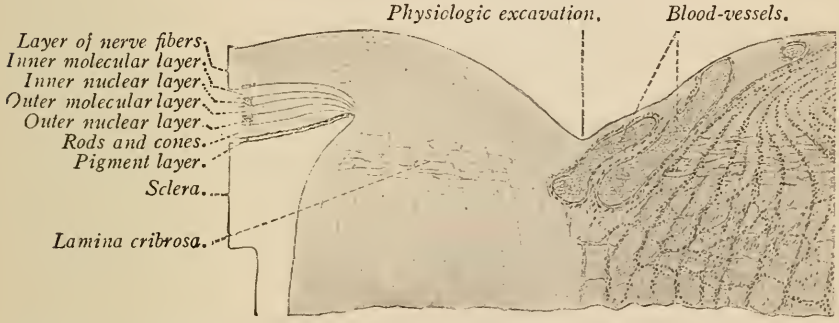


Fig. 294.—Section through point of entrance of human optic nerve (Böhm and Davidoff).

cause of this and the fact that the fibers curve radially, there is produced a deep circular depression in this region. At this point the retina is absent, the choroid coat is interrupted, while connective-tissue fibers of the sclera, called the *lamina cribrosa*, interlace and cross the optic fibers.

3. The *ora serrata* is that portion of the retina that marks the posterior limit of the ciliary body. At this point there is a rapid diminution of the retinal layers until but two rows of cells remain, the outer one pigmented. The optic fibers and visual cells

disappear first. Then the outer molecular layer is lost, so that the nuclear layers become confluent. Ultimately but two rows of cells remain, which are continued over the ciliary body as the *pars ciliaris retinæ*, already mentioned in the description of the ciliary body. The ora serrata forms a zigzag line which marks the posterior border of the ciliary folds.

The *iridica retinæ* has already been described in connection with the description of the iris.

REFRACTING MEDIA.

The *refracting media* of the eye are the cornea, aqueous humor, lens, and the vitreous humor. The cornea is described on another page.

1. The **aqueous humor** is a structureless fluid resembling lymph that fills the chamber of the eye in front of the lens. The iris is suspended in this fluid and divides the chamber into an *anterior* and a *posterior* compartment. The fluid is largely a secretion from epithelial cells, or, according to some, from epithelial glands said to be located in the region of the ciliary body. The aqueous humor is replaced if accidentally lost.

2. **The Lens.**—The origin of the lens has already been described as an ectodermal invagination in the form of a vesicle. The cells of the posterior wall of this vesicle form the bulk of the lens. These cells become long and slender and are known as the *lens fibers*, while the cells of the anterior wall remain low and cubical and form the *anterior epithelium* of the lens. Surrounding the lens on all sides is the *lens capsule*. This capsule is a homogeneous membrane,

thicker on the anterior surface of the lens than on the posterior, and with certain reagents appears to be made up of lamellæ. The latter connect with fibers of the suspensory ligament.

In adults the anterior epithelium forms a single layer of flattened or cubical cells which extend as far

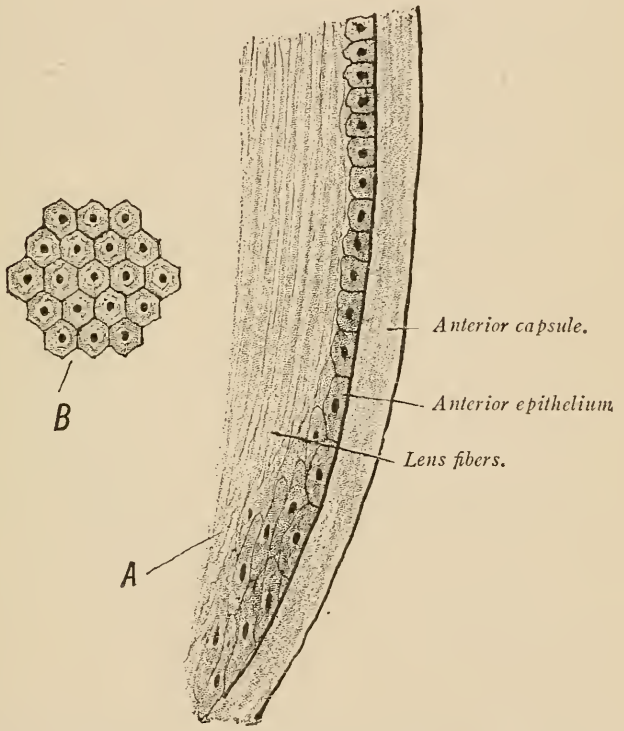


Fig. 295.—Crystalline lens: *A*, longitudinal fibers; *B*, posterior surface view of anterior epithelium (Leroy).

as the equatorial margin of the lens. At this margin the cells increase in height to form the lens fibers. These are flattened hexagonal prisms, thickened at the posterior ends. They pass in a meridional direction from the anterior surface backward, and are

held together by a small amount of cement substance.

The *suspensory ligament* connects the capsule of the lens with the epithelium of the ciliary body and the hyaloid membrane of the vitreous humor. From this point the fibers pass forward and inward to become inserted into the capsule of the lens. The insertion occupies a wide zone at the equator of the lens, which reaches some distance on the anterior and posterior surfaces. Between these fibers there is consequently a canal around the lens, divided by septa, the *canal of Petit*, which communicates by minute openings with the anterior chamber.

3. The **vitreous humor** fills the chamber of the eye back of the lens. It is a transparent tissue that contains about 98 per cent. of fluid substance and fine interlacing fibers, as well as a few connective-tissue cells and leucocytes. Toward the surface the fibers are more densely arranged, forming the *hyaloid membrane* which encloses the entire vitreous body. The origin of the vitreous humor has been described in connection with the developmental history of the eye.

BLOOD-VESSELS OF THE EYE.

The *arteries* of the choroid are derived from the short posterior ciliary, the long ciliary, and the anterior ciliary arteries. The short posterior penetrate the sclera in the vicinity of the optic nerve, and supply blood to the choroid of that region. These arteries also anastomose with branches from the retinal vessels. The *long posterior ciliary* penetrates

the sclera near the optic nerve, and course forward between the choroid and the sclera to the ciliary body. It supplies blood to the ciliary muscles, the ciliary processes, and the iris. The *anterior ciliary arteries* lie close to the straight ocular muscles and penetrate the sclera near the sclerocorneal junction. They give off branches to the iris and the ciliary body, anastomosing with branches from the long posterior ciliary artery. Veins return the blood from these regions and bear the same names as the arteries they accompany.

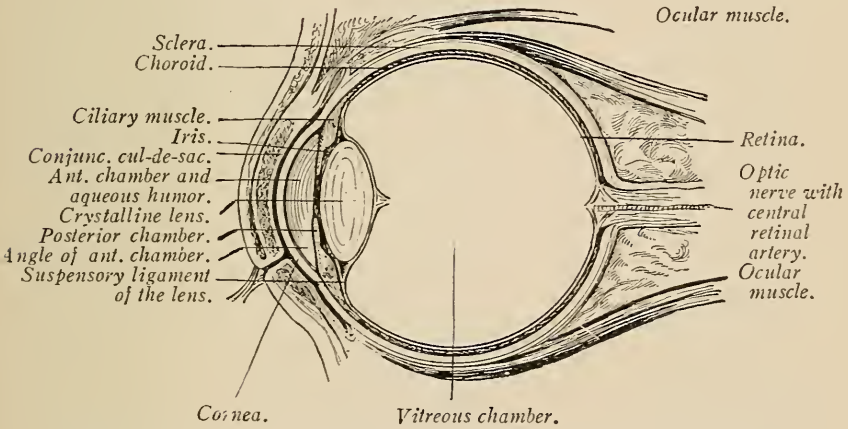


Fig. 296.—Vertical section through the eyeball and lids (Pyle).

The *retina* is supplied with blood from a central artery and vein that enter and leave the retina at the optic papilla, or blind spot. Each divides into a superior and inferior papillary artery and vein. The latter again divide into two branches, making in all four arteries and four veins known according to their position as *superior* and *inferior nasal*, and *superior* and *inferior temporal* vessels. Within the retina

itself a coarse plexus of vessels blends with the nerve fiber layer. This connects with a fine network lying

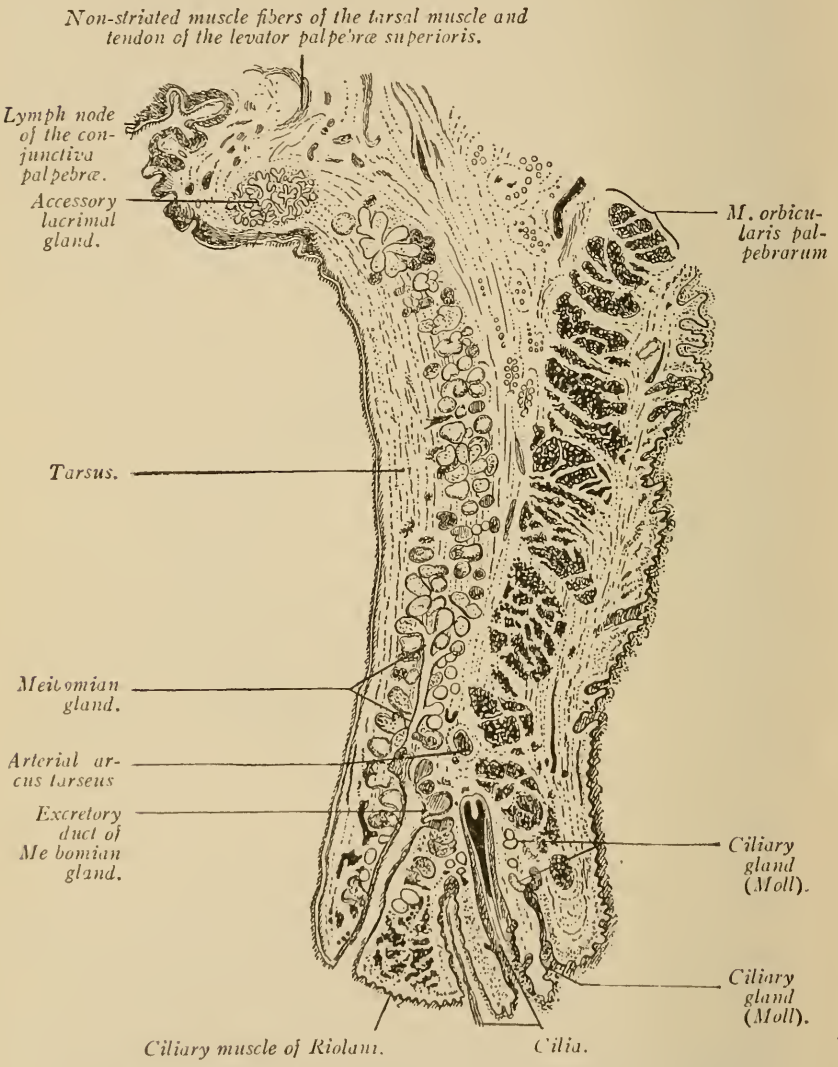

Non-striated muscle fibers of the tarsal muscle and tendon of the levator palpebræ superioris.
Lymph node of the conjunctiva palpebræ.
Accessory lacrimal gland.
M. orbicularis palpebrarum
Tarsus.
Meibomian gland.
Arterial arcus tarseus
Excretory duct of Meibomian gland.
Ciliary gland (Moll).
Ciliary gland (Moll).
Ciliary muscle of Riolani.
Cilia.

Fig. 297.—Vertical section of the upper eyelid of man (Sobotta.)

within the inner nuclear layer The visual cell layer is non-vascular.

The *eyelids* are two movable folds of the skin whose inner surface is covered by a mucous membrane, the *conjunctiva*. The skin on the outer surface is thin, movable, and presents fine hairs with small sebaceous glands, and also a few sweat glands. At the lid margin papillæ are developed and the epidermis is thickened. Along the outer border there are two or three rows of large hairs, the *eyelashes*, the posterior row of which possesses sebaceous glands and modified sweat glands, called the *glands of Moll*. The eyelids are further provided each with twenty-five to thirty large glands, known as *Meibomian* or *tarsal glands*, whose ducts open on the palpebral margin just internal to the eyelashes. Each gland has a large central duct lined by stratified epithelium and into which numerous branched alveoli open. The latter resemble the alveoli of sebaceous glands. The *Meibomian* glands lie close to the internal surface of the eyelids and their cells undergo a fatty change and give out a fat-containing secretion.

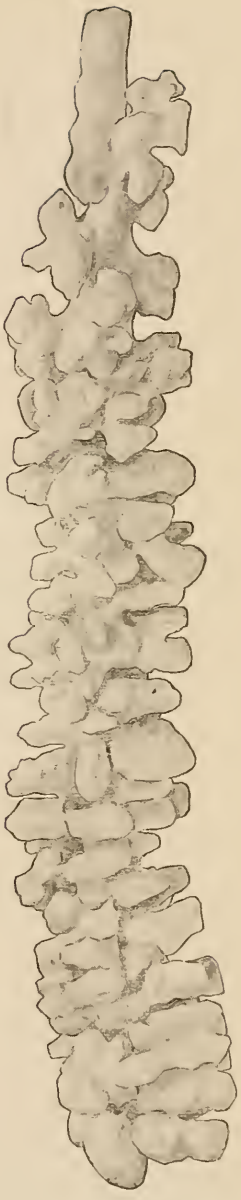


Fig. 298.—Meibomian or tarsal gland, reconstructed after Born's wax-plate method (Huber).

In each lid there exists a frame-

work of condensed fibrous tissue, which gives consistency and shape to the lid, and is termed the *tarsal plate*, or *tarsus*. The *orbicularis oculi* muscle lies beneath the subcutaneous tissue of the outer surface and is composed of voluntary muscle fibers that arch between the angles of the eyelids.

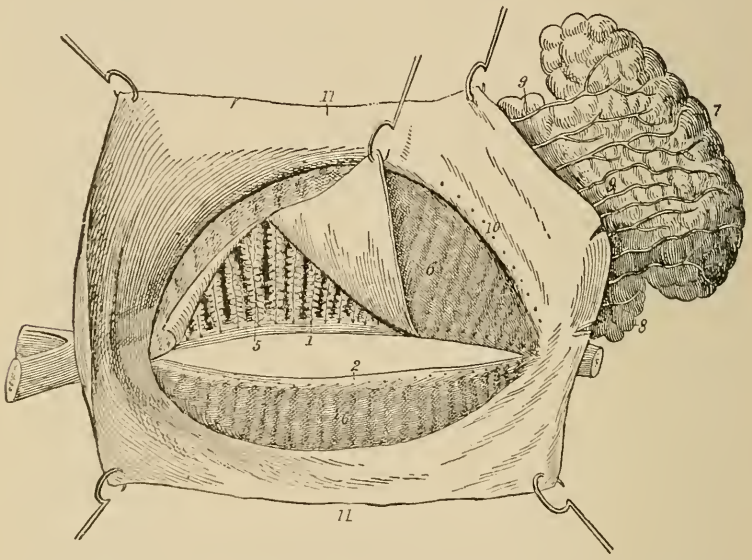


Fig. 299.—Lacrimal and Meibomian glands, the latter viewed from the posterior surface of the eyelids. (The conjunctiva of the upper lid has been partially dissected off, and is raised so as to show the Meibomian glands beneath.) *1*, Free border of upper, and *2*, free border of lower lid, with openings of the Meibomian glands; *5*, Meibomian glands exposed, and *6*, as seen through conjunctiva; *7*, *8*, lacrimal gland; *9*, its excretory ducts, with *10*, their openings in the conjunctival cul-de-sac; *11*, conjunctiva (Testut).

The *conjunctiva* is a mucous membrane that lines the inner surface of the eyelids and is reflected over the front of the eye. Over the cornea it forms the anterior stratified epithelium, and has already been described. The line along which it is reflected on to the globe of the eye is called the *fornix*. The pal-

pebral portion adheres intimately to the tarsal plate and presents numerous papillæ. It is covered by a layer of columnar cells beneath the bases of which are small flattened cells. Goblet cells are to be found among these cells. Over the globe of the eye it adheres closely to the sclera, and this portion of the conjunctiva is perfectly smooth and is composed of stratified squamous epithelium. The conjunctiva that clothes the eyelid is thinner than that which covers the cornea and any foreign particle, therefore, tends to cling to the eyelid rather than to the eye.

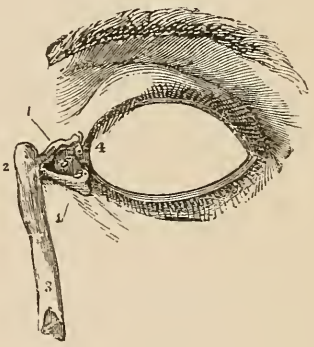


Fig. 300.—1, Canaliculus; 2, lacrimal sac; 3, nasal duct; 4, plica semilunaris; 5, caruncula lacrimalis (Leidy).

The *Lacrimal Apparatus.*—This consists of (1) the lacrimal or tear gland, (2) the lacrimal canals, and (3) lacrimal sac, or nasal duct.

The *lacrimal gland* is a branched tubular gland situated in the upper and outer part of the orbital cavity. Its structure resembles that of a serous gland. The ducts, which are numerous, are clothed with stratified epithelium and open on the conjunctival surface, over which the secretion is evenly distributed by the action of the eyelids.

The *lacrimal canals* begin as two minute orifices at the apices of the papillæ lacrimales situated near the inner canthus. They are lined by stratified epithelium and open directly into the lacrimal sac. The latter is lined with simple pseudostratified epi-

thelium, having two strata of nuclei, and represents the upper expanded portion of the nasal duct. This duct has a similar epithelium and opens into the inferior meatus of the nose. Ciliated epithelium has been described as being present in the nasal duct, and also mucous glands in the lower parts.

CHAPTER XV.

THE ORGAN OF HEARING.

The *organ of hearing* consists of three portions,—external, middle, and internal ear, the last being the essential part, as within this are the peripheral terminations of the auditory nerve.

1. **The External Ear.**—The *pinna* or *auricle* projects from the side of the head and is covered with a thin layer of skin, in which are found hairs, sebaceous glands, and sweat glands. A cartilage matrix of this portion is of the elastic variety with interposed areas of non-elastic cartilage. The lower lobe is free from cartilage and is composed of adipose tissue. The *external auditory meatus* is the passage leading inward from the concha as far as the tympanic membrane. Its average length is about one inch. This tube may be divided into an external cartilaginous portion and an internal osseous portion. The skin lining the cartilaginous portion is clothed with coarse hairs and possesses modified sweat glands called *ceruminous glands*. These are branched, of the tubulo-alveolar variety, and empty into hair follicles near the surface of the skin, or on the surface of the skin in the neighborhood of the hair follicles. The skin of the osseous portion is supplied with neither hair nor glands, but possesses slender papillæ.

At the bottom of the auditory canal is the *tympanic membrane*. It is an elliptical disc placed at an oblique angle to the ear canal, with its antero-inferior border most distant from the outer orifice. This membrane is composed of three layers, an external cutaneous, a middle fibrous, and an inner mucous. The external layer is continuous with the integumentary lining of the meatus and consists of a thin layer of cutis covered by epidermis. The middle layer, or membrana propria, consists of two sets of fibers,—external or radial fibers next to the integument, and internal or circular fibers next to the inner mucous lining. The circular fibers are numerous near the circumference but scattered and few in number near the center. In the upper and anterior margin of the membrane is a small triangular area that is thin and lax and is called the *pars flaccida*. The main portion of the membrane is, on the other hand, tightly stretched and termed the *pars tensa*. Both radial and circular fibers are absent from the pars flaccida.

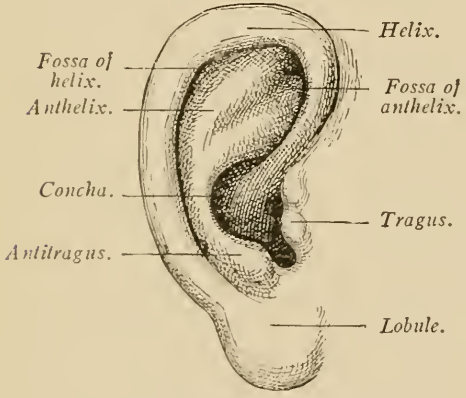


Fig. 301.—External ear (Randall).

2. **The Middle Ear.**—The *middle ear*, or *tympanic cavity*, is a small air chamber in the tympanic bone, intervening between the inner end of the external auditory meatus and the outer wall of the internal

ear or labyrinth. It is lined by a mucous membrane and contains the bones of the ear, *malleus*, *incus*, and *stapes*. The mucous membrane is folded over these ossicles and has a pseudostratified ciliated epithelium, having two strata of nuclei. Cilia are, however, absent on the surface of the auditory ossicles, their ligaments, and the tympanic membrane. The

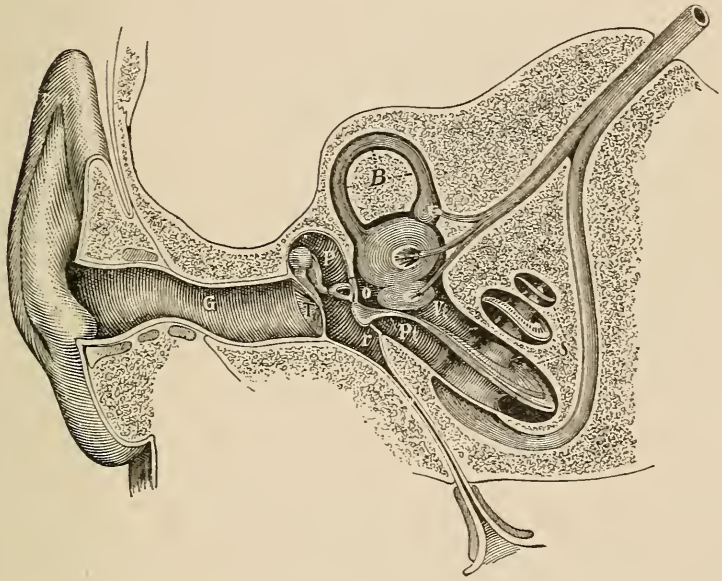


Fig. 302.—Semidiagrammatic section through the right ear: *G*, External auditory meatus; *T*, membrana tympani; *P*, tympanic cavity; *o*, fenestra ovalis; *r*, fenestra rotunda; *B*, semicircular canal; *S*, cochlea; *Vt*, scala vestibuli; *Pt*, scala tympani (Czermak.)

tympanic cavity communicates with the mouth by a narrow canal, the *Eustachian tube*, which transmits air and conveys mucous secretion from the middle ear. This tube is about one and one-half inches in length and is directed downward and inward from the anterior part of the tympanum to open on the

upper part of the nasopharynx by a wide orifice. Its anterior part, about one inch in length, is enclosed in cartilage, while its posterior portion is encased in bone. The mucous membrane is ciliated and glands are absent.

3. **The Internal Ear.**—The *internal ear* is the essential part of the organ of hearing and consists of a *bony* and a *membranous labyrinth.*

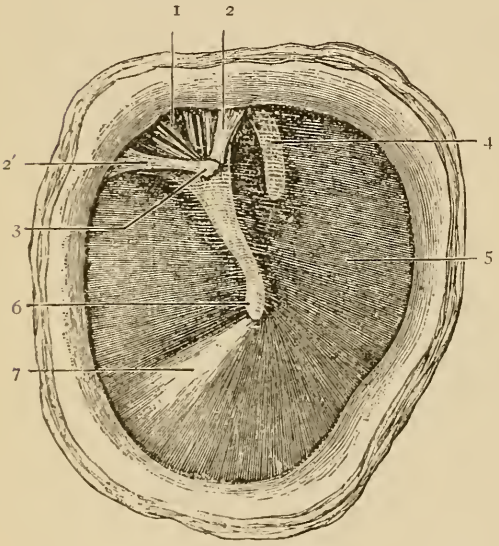


Fig. 303.—Otoscopic view of left membrana tympani: 1, Membrana flaccida; 2, 2′, folds bounding the former; 3, reflection from processus brevis of malleus; 4, processus longus of incus (occasionally seen); 5, membrana tympani; 6, umbo and end of manubrium; 7, pyramid of light (Morris).

The latter is contained within the former and represents the same general shape, the two being separated by a lymph space containing the perilymph. A series of cavities constitute the bony labyrinth, which are named from before backwards—*cochlea, vestibule,* and *semicircular canals.* The membranous labyrinth situated within these cavities consists of the *membranous cochlea, utriculus,* and *sacculus,* and *membranous semicircular canals.*

(1) *Vestibule, Utriculus,* and *Sacculus.*—The *vestibule* forms the central portion of the bony labyrinth

and communicates behind with the bony semicircular canals, and in front with the cochlea. Its outer wall forms the inner wall of the tympanic cavity, and in it is seen the *fenestra ovalis*, into which the foot of the stapes is adjusted. The posterior part of the vestibule receives five apertures that lead to the semicircular canals, while its anterior part leads by an elliptical opening into the scala vestibuli of the cochlea.

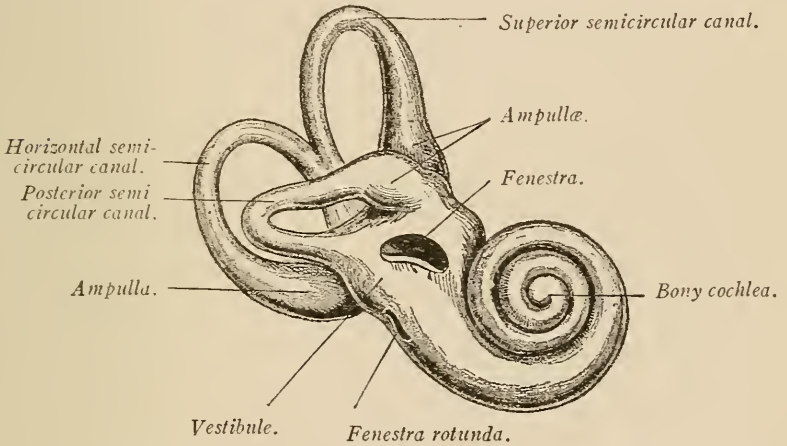


Fig. 304.—Right bony labyrinth, viewed from outer side: The figure represents the appearance produced by removing the petrous portion of the temporal bone down to the denser layer immediately surrounding the labyrinth (from Quain, after Sömmering).

The *utriculus* and *sacculus* are two sac-like structures enclosed in the bony vestibule. The two are indirectly connected by the *ductus endolymphaticus*, which is a Y-shaped channel that terminates in a blind recess, the *saccus endolymphaticus*. The latter lies against the dura on the posterior surface of the temporal bone.

The *utriculus* is larger than the sacculus and occu-

pies the postero-superior portion of the bony vestibule. It communicates by five apertures with the membranous semicircular canals. Its wall is composed of fibrous tissue, lined internally with a single layer of columnar epithelium. The floor and anterior wall is thickened to form the *macula acustica utriculi*, which is innervated by fibers of the auditory nerve. The epithelium of this region is composed

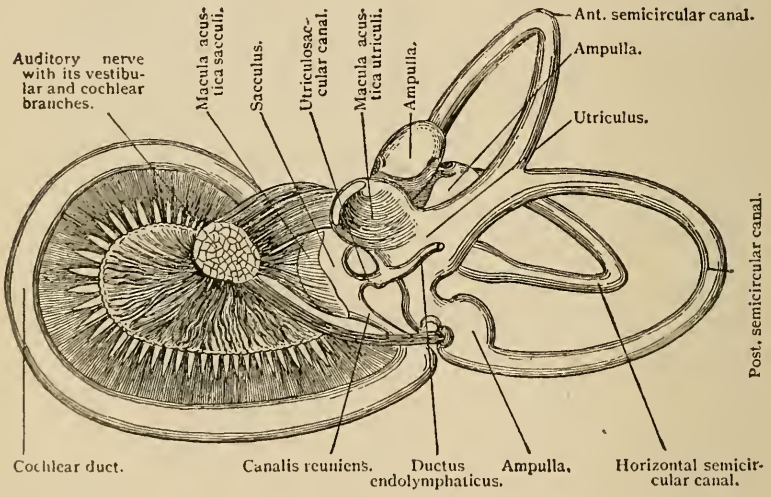


Fig. 305.—Membranous labyrinth of the right ear from five-months human embryo (from Schwalbe, after Retzius).

of two kinds of cells: (1) slender sustentacular cells resting on a basement membrane, and (2) hair cells, or auditory cells. The latter support a number of stiff hairs and constitute the neuro-epithelium, around which arborize the neurons of the auditory nerve. Crystals of calcium carbonate, known as *otoliths*, are found on the surface of the epithelium.

The *sacculus* occupies the lower portion and fore

part of the bony vestibule. It is oval in shape, smaller than the utriculus, its longest diameter measuring about 3 mm. From its lowest part a short canal, the *duct of Hensen*, opens into the ductus cochlearis. Anteriorly there is an oval, whitish thickening, the *macula acustica sacculi*, innervated by the neurons of the auditory nerve. The histology of the sacculus is like that of the utriculus.

(2) *Semicircular Canals.*—There are three osseous canals situated behind and above the vestibule. The *superior* canal is vertical, the *external* is horizontal, and the *posterior* is vertical. They open into the vestibule by five apertures, since the inner extremity of the superior and the upper extremity of the posterior join to form a common duct, the *canalis communis.* Each canal presents an enlargement or osseous ampulla near its origin with the vestibule. The *membranous semicircular canals* partly fill the bony canals, to which they conform. The peripheral border of each canal is fixed to the periosteum of the bony canals while the opposite part is free. Each canal is dilated in the bony ampulla to form a *membranous ampulla.* These canals communicate with the utriculus and possess a fibrous wall clothed with simple pavement epithelium, excepting in the ampullæ, where it is columnar. In the latter slender sustentacular cells intervene between shorter neuro-epithelial cells, or hair cells, similar to those of the maculæ. The neurons of the auditory nerve arborize around the bases of the hair cells.

(3) *The Bony and Membranous Cochlea.*—The *bony cochlea* assumes the form of a short cone and con-

sists of a spirally arranged tube which forms from two and one-half to two and three-quarter coils around a central pillar termed the *modiolus*. The length of this tube is about 30 mm. and its diameter, near the base of the cochlea, about 2 mm. The

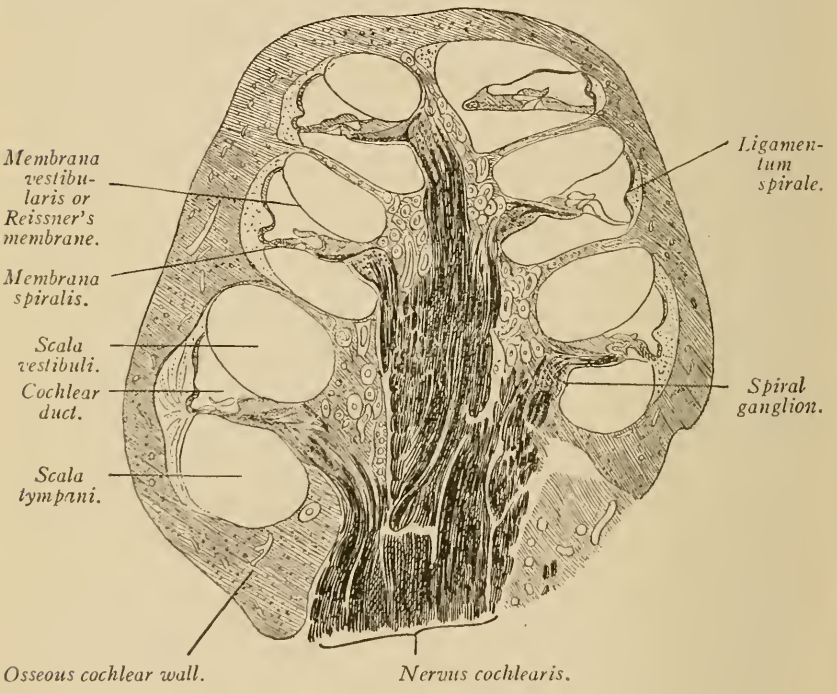


Fig. 306.—Longitudinal section of the cochlea of a cat. This figure gives a general view of the cochlea. The cochlear duct is met with six times in the section (Sobotta).

modiolus is about 3 mm. in height and transmits the nerve. A flat shelf of bone, the *lamina spiralis*, winds around the modiolus like the thread of a screw, and projects about half-way into the cochlear tube and thus incompletely divides this tube into two passages, of which the upper is named the *scala vesti-*

buli, and the lower the *scala tympani*. A membrane—the *membrana basilaris*—stretches from the free edge of the bony lamina spiralis to the outer wall of the cochlea and completes the scala vestibuli

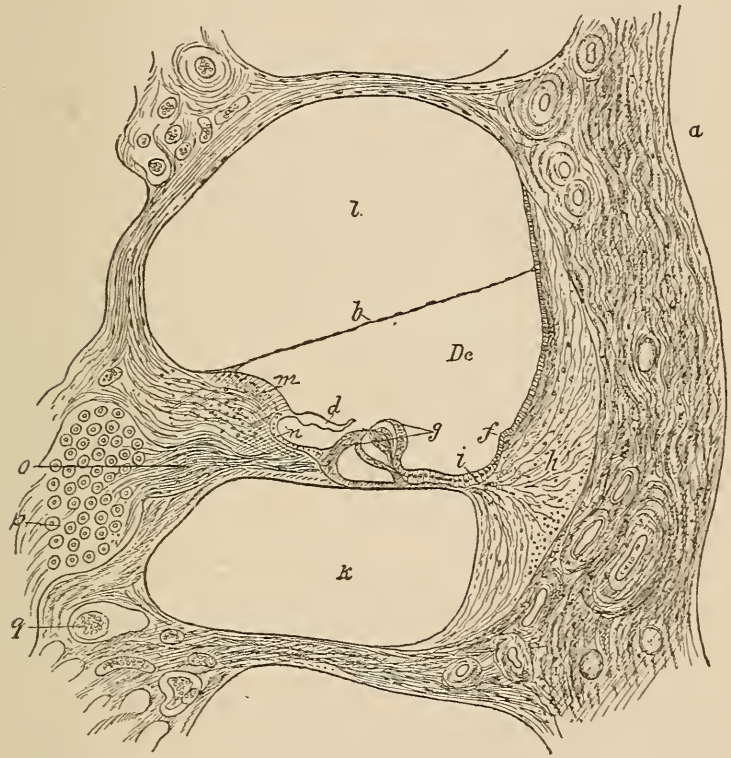


Fig. 307.—Section through one of the turns of the osseous and membranous cochlear ducts of the cochlea of a guinea-pig: *l*, Scala vestibuli; *m*, labium vestibulare of the limbus; *n*, sulcus spiralis internus; *o*, nerve fibers lying in the lamina spiralis; *p*, ganglion cells; *q*, blood-vessels; *a*, bone; *b*, Reissner's membrane; *Dc*, ductus cochlearis; *d*, Corti's membrane; *f*, prominentia spiralis; *g*, organ of Corti; *h*, ligamentum spirale; *i*, crista basilaris; *k*, scala tympani (Böhm and Davidoff).

and the scala tympani, but the two communicate at the apex of the cochlea. The scala tympani begins at the *fenestra rotunda*, in the inner wall of the

tympanum just below the fenestra ovalis, and the scala vestibuli leads to the perilymphatic space of the vestibule. The fenestra rotunda is closed by the tympanic membrane.

From what has been stated it is evident that an injection into the scala tympani through the foramen rotunda will pass into the scala vestibuli at the apex of the cochlea, and travel down the passage above the lamina spiralis to ultimately reach the perilymphatic space of the vestibule and exert pressure against the base of the stapes through the fenestra ovalis.

The *membranous cochlea* (ductus cochlearis or scala media) forms a spiral canal inside the bony cochlea, and ends at the apex of the latter in a blind extremity, the *lagena*. This scala media lies near the free margin of the lamina spiralis and just above the membrana basilaris. It thus forms a spiral tube that gradually increases in size from its lower to its upper or distal end. Its lower end communicates with the sacculus through the *ductus reuniens of Hensen*. Triangular in transverse section it has a roof, called *Reissner's membrane*, which separates it from the scala vestibuli. Its outer wall is the periosteal lining of the bony cochlea, while its floor is the outer border of the lamina spiralis and the membrana basilaris. This membranous labyrinth is clothed throughout its whole length by a single layer of epithelial cells.

Reissner's membrane consists of an exceedingly thin connective-tissue lamella lined on the vestibular side with a single layer of endothelial cells, and on the

cochlear duct by a single layer of flat epithelial cells.

The outer wall of the scala media is the periosteal lining of the bony cochlea which is thickened and modified to form what is termed the *ligamentum spirale cochleæ.* The ligament has a projection, the crista basilaris, to which the outer edge of the membrana basilaris is attached. The inner surface of

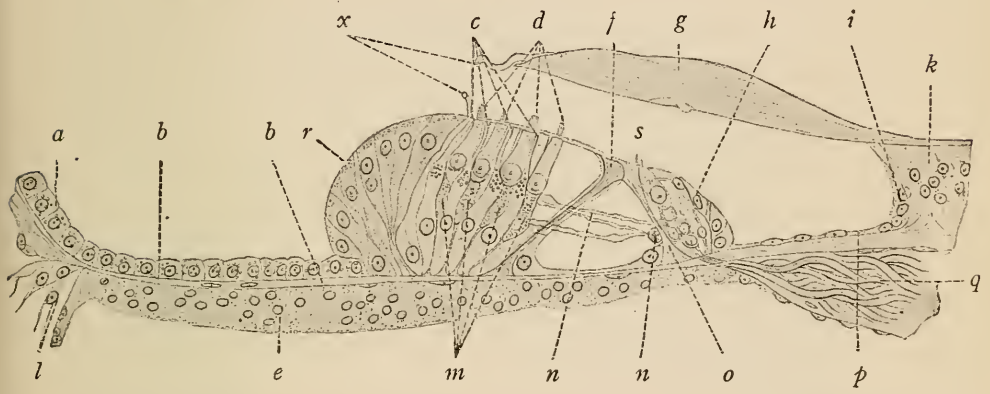


Fig. 308.—Organ of Corti: At *x* the tectorial membrane is raised; *c*, outer sustentacular cells; *d*, outer auditory cells; *f*, outer pillar cells; *g*, tectorial membrane; *h*, inner sustentacular cells; *i*,*p*, epithelium of the sulcus spiralis internus; *k*, labium vestibulare; *e*, tympanic investing layer; *m*, outer auditory cells; *n*, *n*, nerve fibers which extend through the tunnel of Corti; *o*, inner pillar cell; *q*, nerve fibers; *b*, *b*, basilar membrane; *a*, epithelium of the sulcus spiralis externus; *r*, cells of Hensen; *s*, inner auditory cell; *l*, ligamentum spirale (after Retzius).

this wall is clothed with simple epithelium of the columnar type, which in places appears to be stratified and to possess darkly granulated cells.

On the floor of the scala media and resting on the basilar membrane is the complicated structure termed the *organ of Corti.* This consists of the following structures: (1) Corti's rods or pillars; (2)

hair cells (inner and outer); (3) supporting cells of Deiters; (4) the cells of Hensen and Claudius; (5) the lamina reticularis, and (6) a cuticular membrane, the membrana tectoria.

1. The *rods of Corti* form two rows, an inner and an outer. The bases of the two rows are planted on the membrana basilaris, some little distance apart, and the outer ends come in contact so that between the two rows above and the basilar membrane below there is enclosed a triangular tunnel, the *tunnel of Corti*. This tunnel increases both in height and width toward the apex of the cochlea. The inner rods number nearly six thousand. The outer rods number about four thousand, and are longer than the inner. They are also more inclined toward the basilar membrane and form with it an angle of about forty degrees.

2. The *hair cells* are placed on each side of the rods and thus form an inner and an outer set. The inner hair cells form a single row and number about three thousand five hundred, so that each cell is supported by a little more than one rod. Their free extremities are surmounted by about twenty fine hair-like processes arranged in the form of a crescent. Each cell is oval and contains a large nucleus. The lower end is rounded and reaches about half-way down the rod, and in contact with this end are the arborizations of the nerve terminations. To the inner side of these cells are several rows of columnar cells that function as supports. The outer hair cells number about twelve thousand, and form three rows in the basal coil and about four rows in the upper two

coils. The free extremity of each cell supports some twenty hair-like processes, while the outer extremity reaches half-way to the basilar membrane and is in contact with nerve arborizations.

3. *Deiters' supporting cells* alternate with the rows of the outer hair cells. Their lower ends expand upon the basilar membrane, and the upper end tapers

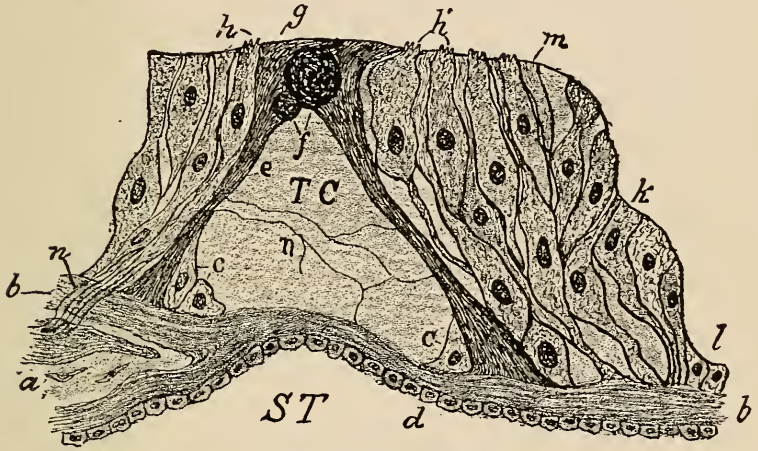


Fig. 309.—Section of Corti's organ from guinea-pig's cochlea: *ST*, scala tympani; *TC*, tunnel of Corti; *a*, bony tissue or spiral lamina; *b*, *b*, fibrous tissue covering same continued as substantia propria of basilar membrane; *c*, *c*, protoplasmic envelope of Corti's pillars (*e*, *e*,); *d*, endothelial plates; *f*, heads of pillars containing oval areas; *g*, head plates of pillars; *h*, *h'*, inner and outer hair cells; *m*, membrana reticularis; *k*, *l*, cells of Hensen and Claudius; *n*, *n*, nerve fibers; *i*, cells of Deiters (after Piersol).

and extends to the free surface of the hair cells. Each cell has a nucleus near its middle and contains a bright thread-like structure, called the *supporting fiber*.

4. The *cells of Hensen* are outer supporting cells and consist of several rows just outside of Deiters' cells, where they form a well-marked elevation on the floor

of the scala media. The columnar cells just external to this elevation are named the *cells of Claudius*.

5. The *lamina reticularis* is a thin cuticular structure which lies over Corti's organ and extends from the outer rods as far as Hensen's cells. This membrane has numerous small apertures into which the outer hair cells project.

6. The *membrana tectoria* is an elastic membrane attached to the free margin of the lamina spiralis and reaching outward as far as the outer row of hair cells. This membrane has no nuclei and shows fine radial striations. The membrane is supposed to act as a damper to the hair cells.

The Auditory Nerve.—The auditory nerve divides into two main parts, the *ramus vestibularis* and the *ramus cochlearis*. The vestibularis divides into three branches which are the macula acustica, utriculi, and the ampullæ of the inferior and external semicircular canals. The ramus cochlearis supplies a branch to the macula acustica sacculi and one to the ampulla of the posterior semicircular canal. The remainder of the ramus cochlearis is distributed to the hair cells of Corti's organ. Near the base of the osseous spiral lamina there is situated, in a special bony canal, a ganglion called the *spiral ganglion* of the cochlea. The ganglion cells are bipolar, having a dendrite that extends inward through the lamina spiralis to the organ of Corti, and a neuraxis that passes out the modiolus and thence to the medulla. Some of the dendritic processes pass through the tunnel of Corti, so called *tunnel fibers*, to reach the outer hair cells.

DEVELOPMENT OF THE LABYRINTH.

The epithelial lining of the membranous labyrinth is derived from the ectoderm and develops as a vesicular invagination on each side of the epencephalon. After being constricted off from the ectoderm this vesicle develops a dorsomesial evagination, which gradually grows larger and becomes the ductus endo-

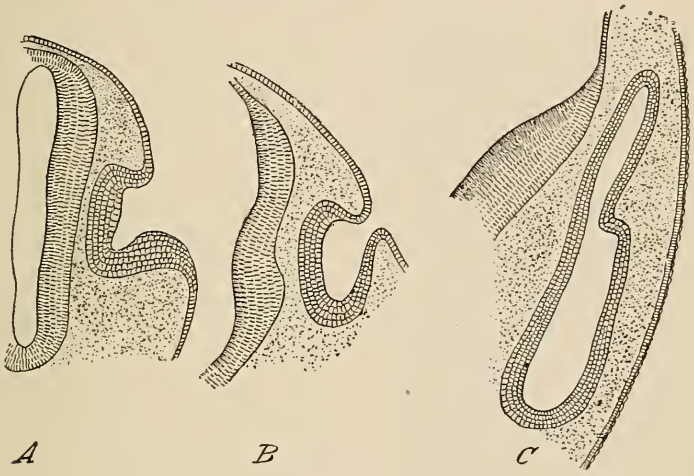


Fig. 310.—Three transverse sections showing development of otic vesicle of human embryo (Tourneux): *A*, from embryo of 3 mm., showing auditory pit; *B*, from embryo of 4 mm., showing the transformation of the pit into the otic vesicle; *C*, from embryo of 6 mm., showing otic vesicle detached from surface ectoderm, and presenting a posterior diverticulum, the recessus vestibuli.

lymphaticus. By means of folds and constrictions the dorsal utriculus and ventral sacculus are formed, and also the semicircular canals which connect with the utriculus. The membranous cochlea or scala media grows both in a longitudinal and a spiral direction, retaining its connection with the sacculus through the canalis reuniens. This complex mem-

branous labyrinth becomes invested with developing bone, and is filled with endolymph and surrounded with perilymph. The developmental history of the middle and external ear is closely associated with that of the first gill cleft of which they primarily form an associate part.

CHAPTER XVI.

OLFACTORY ORGAN.

The *olfactory* region may be divided into the vestibule, respiratory organ, and the olfactory organ.

1. The *vestibule* is covered with a continuation of the skin, which gradually takes on the character of a mucous membrane. The epithelium is of a stratified squamous variety, and presents hairs, sebaceous glands, and mucous glands. The vestibule comprises the region of the anterior nares.

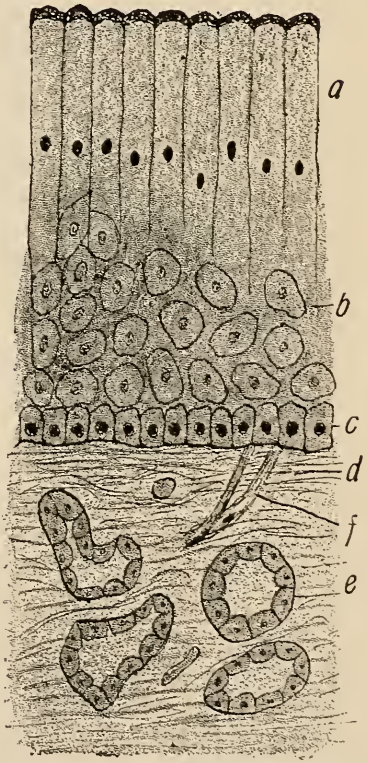


Fig. 311.—Olfactory mucous membrane; *a*, sustentacular cells; *b*, olfactory cells; *c*, basal cells; *d*, submucous fibrous tissue; *e*, glands of Bowman; *f*, nerve fibers (Leroy).

2. The *respiratory region* is lined by ciliated epithelial cells, the nuclei of which are placed at various levels. Hairs and sebaceous glands are absent, but branched alveolar glands having mucous and serous cells are present. Numerous leukocytes are usually found upon the surface.

3. The *olfactory region* is usually confined to the superior turbinated bone and to the adjacent nasal septum. In the fresh condition the region may be

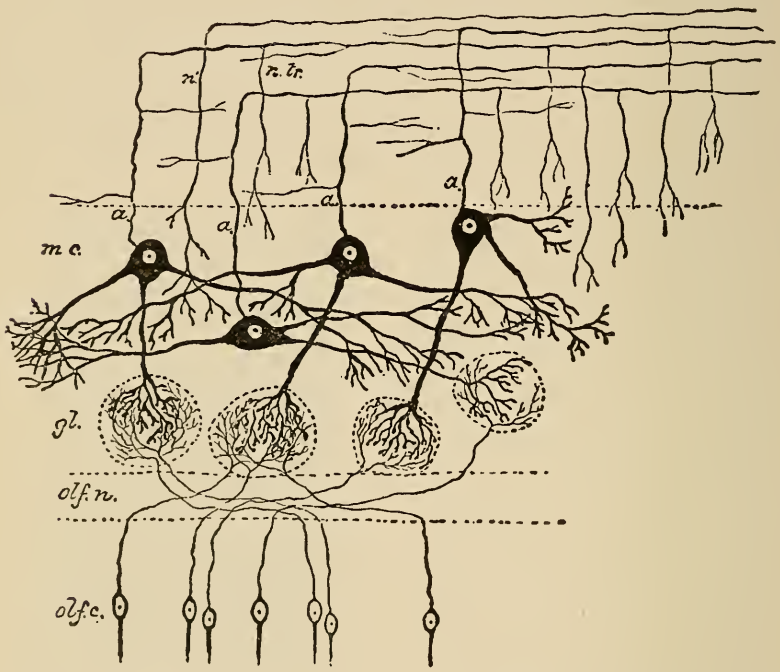


Fig. 312.—Diagram of the connections of cells and fibers in the olfactory bulb: *olf. c*, cells of the olfactory mucous membrane; *olf. n*, deepest layer of the bulb, composed of the olfactory nerve fibers which are prolonged from the olfactory cells; *gl*, olfactory glomeruli, containing arborization of the olfactory nerve fibers and of the dendrons of the mitral cells; *mc*, mitral cells; *a*, thin axis-cylinder process passing toward the nerve-fiber layer, *n. tr*, of the bulb to become continuous with fibers of the olfactory tract; these axis-cylinder processes are seen to give off collaterals, some of which pass again into the deeper layers of the bulb; *n'*, a nerve fiber from the olfactory tract ramifying in the gray matter of the bulb (Schäfer).

distinguished by its yellow color, which is due to pigment in the sustentacular epithelial cells.

The *olfactory cells* are true bipolar ganglion cells. The upper process of these cells reaches to the free

surface of the epithelial layer and is short. It terminates in six to eight short firm hairs. The lower thinner process is a neuraxone which passes through the cribriform plate to terminate in telodendria in the region of the olfactory bulb. The *sustentacular cells* are long columnar elements with oval nuclei. They give support to the ganglion cells.

Large branched tubular glands are present, called the *glands of Bowman.* They secrete an albuminous or serous fluid. Beneath the epithelium there is a rich supply of capillary blood-vessels and lymphatics. Fibers from the trigeminal nerve terminate in telodendria among the epithelial cells of the entire olfactory region.

CHAPTER XVII.

LABORATORY DIRECTIONS.

PREPARATION OF MATERIAL.

I. **Spreads.**—Thin spreads or smears are made upon cover glasses or on glass slides. The specimens are then studied, stained or unstained, but always in some liquid medium. They may be fixed and mounted permanently by treating the preparations just as if they were sections. Blood, marrow, nerve cells from brain or cord, and scrapings from organs, as the liver, may be prepared in this way.

II. **Teasing.**—Muscle, tendon and nerve fibers are easily prepared in this way. The teasing, or spreading, may be done in water and glycerin, or small pieces may be dehydrated with alcohol and then teased in oil, or even in balsam, thus making a permanent mount. Alcohol and oil harden the tissues, and satisfactory teasing is therefore more difficult.

III. **Dissociation or Maceration of Tissue Elements—**

1. Alcohol, 25 per cent.; time, twenty-four or forty-eight hours.
2. Strong acids, as hydrochloric or nitric; time, twenty-four hours.
3. Caustic potash, 25 per cent.; time, ten to thirty minutes.

To obtain columnar and goblet cells of the intestine,

remove several inches of the colon, clean carefully by passing water through it, and then distend the piece with 25 per cent. alcohol, ligating both ends. Next day open the bowel and make light scrapings from the mucous surface and place these in a vial containing equal parts of alcohol (50 per cent.) and glycerin. Shake the vial and the cells will disseminate throughout the fluid. The 25 per cent. alcohol dissolves the cement that holds these epithelial cells together. If desired, a little stain may be added to the glycerin preparation.

The epithelium of the bladder may be obtained in the same manner, by distending the organ with 25 per cent. alcohol; also, the ciliated cells of the trachea, although in this case no distention is possible. All these cells come away very easily, and the scraping must be carefully done.

Tubules of the kidney are readily obtained by treating small pieces with acid. In twenty-four hours, remove the pieces to equal parts of alcohol and glycerin, and shake. A drop of this will show all forms of tubules and glomeruli. The former are practically equivalent to epithelial casts, clinically so important in urinary analysis.

The caustic potash reaction is more rapid. Pieces of tissue may be treated with this on the glass slide and examined in the fluid. Care must be observed that the alkali does not get on the lens of the microscope.

IV. To Prepare Tissue for Sectioning in Celloidin or Paraffin.

1. **Fixing and Hardening.** — Fixing consists in

rapidly killing the cell and preserving its constituents, nucleus and cytoplasm, before disintegration can take place. Most fixing agents coagulate the protoplasm and cell contents.

(*a*) *Heat.*—Cover-glass preparations may be fixed by heating them in an oven or over a gas flame to 100° or even 150° C.

(*b*) *Fluids.*

(1) Acids—osmic, 1%; chromic, 1%; nitric, 10%; etc.

(2) Salts—mercuric chloride saturated, potassium bichromate, 3%; etc.

(3) Alcohol, 95%, or absolute.

(4) Formalin, 5%.

Acids and salts may be used separately as above, but as a rule different combinations are used, formulæ of which are given on another page.

(*c*) *Precautions.*

(1) Fix living tissues, if possible.

(2) Fix small pieces, so that fluids may readily penetrate.

(3) Heat hastens the penetration.

(4) Change as often as the fluid becomes cloudy.

(5) Use a large quanitity of fluid (50 to 100 times the volume of the tissue).

2. Washing.

(*a*) *Water.*—If there is a chemical change between the fixing agent and the tissue, use water. This is most frequently the case. The specimens should be very thoroughly washed, preferably in running water, for twenty-four hours or more.

(*b*) *Alcohol.*—When alcohol is indicated, use the

grades 50%, 70%, 95%, and leave in 80%. When ever picric acid forms a part of the fixing agent, alcohol wash must be used.

3. **Dehydrating.**

(*a*) We dehydrate to preserve the tissue from action of bacteria.

(*b*) In order that imbedding fluids, which do not mix with water, may penetrate the tissue. Alcohol, the grades ending with absolute alcohol, is always the agent used.

4. **Imbedding with Celloidin, Evaporation Method.**

(*a*) *Absolute Alcohol and Ether, Equal Parts.*—After thorough dehydration in absolute alcohol, the tissue is transferred to absolute alcohol and ether, equal parts, where it is left for twenty-four hours.

(*b*) *Thin celloidin*, 4%, made by dissolving celloidin shreds in equal parts of absolute alcohol and ether. The tissue may be left any length of time in thin celloidin, the longer the better.

(*c*) *Thick celloidin*, 10%; time, twenty-four hours or longer.

5. **Mounting on Block and Evaporation of Ether.**

(*a*) *Cover surface, of perfectly dry block*, with thin celloidin.

(*b*) *Remove the tissue* from thick celloidin and place upon block, in the proper position for cutting. This is called orienting. A piece like a nerve may have to be supported with needles, and these removed later.

(*c*) *Add thick celloidin*, from time to time, and open any air bubble that may appear. Leave the specimen in air until the ether has evaporated so that the

celloidin does not feel sticky to the touch. The usual time will be ten to twenty minutes.

(*d*) *Transfer to Chloroform Vapor.*—Pour a little chloroform over the bottom of a dish. Set the blocks in this so that the liquid does not reach the tissue. Cover tightly and leave for thirty minutes.

(*e*) *Transfer to chloroform liquid by immersing* the tissue. Time, thirty minutes.

(*f*) Transfer to 80% alcohol, where blocks may be left permanently.

6. **Imbedding with Paraffin or Fusion Method.**

(*a*) *Intermediate Stage.*—The tissue is taken out of absolute alcohol, where it has been thoroughly dehydrated, and is then treated with some fluid that is miscible on the one hand with absolute alcohol, and on the other with paraffin. Liquids used are—

(1) Chloroform.
(2) Cedar-wood oil.
(3) Turpentine.
(4) Xylol.

Tissues left in oils become brittle. From one to two hours are usually sufficient, depending upon the size of the piece to be imbedded. Chloroform will harden the tissue to a less degree than the other fluids.

(*b*) *Melted Paraffin.*—The melting-point of paraffin should vary according to the room temperature where the sections will be cut. The following table gives the relation of melting-point of paraffin to this temperature:

Paraffin melting-point.	*Room temperature.*
45° C.	15° to 17° C. or 60° to 65° F.
48° C.	22° C. or 70° F.
55° C.	24° C. or 75° F.

Tissues are left in melted paraffin from two to six hours.

(*c*) *Solidification of paraffin* may be accomplished by means of—

(1) Watch glasses.
(2) Metallic frames.
(3) Paper trays.
(4) Tea-lead trays.

The paraffin is poured into these trays, and the tissue quickly transferred to it. The piece is then oriented, and as soon as the paraffin has cooled enough to form a crust, the whole block is placed in cold water, where the paraffin is quickly cooled so as to avoid crystallization. The block is then ready to be cut in sections.

A. Advantages of Celloidin Imbedding.

1. No heat is necessary.
2. Large sections may be cut, because penetration is more complete than is the case with paraffin.
3. Unnecessary to remove celloidin to stain; sections are therefore easily handled.

B. Disadvantages of Celloidin Sections.

1. Slow process—at least three days.
2. No thin sections.
3. Celloidin may take the stain, particularly with saffranin.
4. Serial sections difficult to make.
5. More expensive.

C. Advantages of Paraffin Imbedding.

1. Accommodates very small objects.
2. Thinner sections may be cut.
3. Rapid process.
4. Cheaper than celloidin method.

D. Disadvantages of Paraffin Imbedding.

1. Must use heat, which is injurious to tissues.
2. Must remove paraffin to stain sections, and the latter therefore tear easily.
3. Proper room temperature necessary when sections are cut, in order to conform to melting-point of paraffin.

7. **Cutting Sections.**—Use the whole edge of the knife in cutting celloidin sections, and keep the knife wet with 70% alcohol. When cutting paraffin sections, the knife is placed at right angle to the block. Always trim away superfluous paraffin.

8. **Staining celloidin sections.**

1. Alcohol, 95%.
2. Water.
3. Hematoxylin, ten minutes.
4. Water.
5. Acid alcohol, HCl 0.5 to 1%; leave the sections in this until all stain is washed out of the celloidin.
6. Water.
7. Eosin, 0.5% solution, one to three minutes.
8. Alcohol, 35%.
9. Alcohol, 95%.

10. Xylol creosote (beechwood creosote, 20 parts; xylol, 80 parts).

11. Mount in Canada balsam and cover.

The sections must become perfectly transparent in the xylol creosote. If they are cloudy or milky, water is present; and the sections must be returned to alcohol, 95%, and the process repeated. Sections that curl should be flattened out when lifted out of 95% alcohol, because in this the sections are soft. In xylol or in water the sections are hard.

9. **Staining Paraffin Sections.**—Since the paraffin has to be removed the sections first have to be fixed to the glass slide or cover glass.

(1) Spread fixative on slide. Albumin fixative consists of egg albumin and glycerin, equal parts. A very thin spread is all that is necessary. Schællinbaum fixative consists of clove oil 4 parts and thin celloidin 1 part. A thicker spread of this is used.

(2) Place section upon slide and heat gently.

(3) Xylol or turpentine to remove the paraffin.

(4) Absolute alcohol to remove the oil.

(5) Alcohol, 95%.

Stain on the slide, or immerse the whole slide in the stain, following directions as for celloidin sections.

Stain in bulk before imbedding in paraffin whenever this is possible, as then the sections may be mounted from xylol directly into balsam. An excellent way to get sections smooth is to float them on warm water—not so warm as to melt the paraffin—and then lift them out upon the glass slide. Decant surplus water and put away for twenty-four hours to dry. Next day remove paraffin with xylol and stain according to above directions.

Review of Preparing Tissues.

1. Fixing and hardening
2. Washing.
3. Dehydrating.
4. Imbedding in celloidin.
5. Mounting on block and evaporation of ether.
6. Imbedding in paraffin.
7. Cutting sections.
8. Staining celloidin sections.
9. Staining paraffin sections.

The following is a brief outline of the tissues to be prepared for a laboratory course accompanying the text. Special technique is cited whenever indicated, otherwise standard laboratory methods may be employed. This outline is abbreviated and should be expanded according to the skill of the instructor or student and according to the laboratory equipment.

Mitosis.

1. Growing point of onion or lily root tip, hardened in Flemming or corrosive sublimate, and cut in longitudinal section.

2. Testicle of grasshopper taken in June, or ova, or skin stripped from tail of growing tadpoles. Iron nematoxylin stain is excellent.

Epithelium.

1 Isolated epithelial cells from intestine, trachea and bladder (see page 457).

2. Epithelium exfoliated from skin of frog (pieces gathered from water where frogs are kept).

3. Fresh cells scraped from mucous surface of cheek.

4. Sections of intestine, cornea of the eye, and skin.

5. Endothelial cells of mesentery.

Prepare endothelium as follows:

(1) Kill a small animal, as a rat.
(2) Open abdominal cavity.
(3) Wash out cavity with sterile water; do not handle the mesentery.
(4) Fill cavity with $\frac{1}{4}$ per cent. silver nitrate solution, 5 min. See that mesentery is bathed.
(5) Wash cavity with $\frac{1}{4}$ per cent. nitric acid solution, 5 min.
(6) Fill cavity with alcohol 95 per cent. one-half to one hour, as convenient.
(7) Remove mesentery with intestine attached.
(8) Immerse in fresh 95 per cent. alcohol one to twelve hours.
(9) Cut intestine away from mesentery and immerse the latter in fresh 95 per cent. alcohol, one-half to one hour.
(10) Transfer mesentery to clove oil and expose to sunlight in shallow wide dish, three to five hours. Direct sunlight is not good.
(11) Cut mesentery into small pieces and mount in balsam. Handle mesentery as little as possible during the whole process.

Glands.

1. For simple mucous and serous glands make cross sections of the skin of a salamander.

Connective Tissue.

1. Sections of young umbilical cord and of embryos show connective-tissue cells.

2. Sections of fat and teased fresh pieces of fat.

3. Salamander skin, dehydrated and mounted with lower side up shows connective-tissue pigment cells.

4. Brown connective-tissue pigment cells may be scraped from the choroid coat of the eye after removing the retina.

5. Sections and teased preparations of ligamentum nuchæ of the ox.

6. Sections and teased preparations of a tendon.

7. Elastic fibers of the mesentery of a rat.

PREPARATION OF ELASTIC FIBERS.

(1) Fill abdominal cavity of a rat with 95 per cent. alcohol, one hour.

(2) Remove intestine with mesentery attached and place in fresh alcohol.

(3) Cut away the mesentery and mordant with 6 per cent. solution of boric acid.

(4) Stain.

Orcein	1 part.
Alcohol, 95 per cent	100 parts.
Hydrochloric acid	1 part

Stain for one to twelve hours. The fibers should appear dark brown. If stained too deeply, treat with acid alcohol, ½ per cent. hydrochloric acid. If too red, dip the pieces in fifty per cent. alcohol saturated with ammonium picrate.

Cartilage.

1. Cartilage sections may be cut with a razor from bone joints obtained at a meat market.

2. Sections of trachea for hyaline variety. The sections must be cut thin and not overstained.

Bone.

1. Ground sections, mounted dry. A dry white and fat-free bone is the best. With a turning table ring a glass slide with balsam. Before the balsam

sets the bone may be mounted dry by covering with circular cover glass, which sticks to the ring of balsam.

2. Sections of decalcified bone. Place a fresh bone in 95 per cent. alcohol to fix and harden soft parts. Next day begin process of decalcification. Use nitric or hydrochloric acid, $\frac{1}{2}$ to 1 per cent., using a large quantity and changing fluid twice daily. Nitric acid may be used in 1 to 10 per cent. strength. Time required varies from one to seven days. By means of sharp needles it is possible to determine when decalcification is complete. After decalcification wash in running water for twenty-four hours.

Muscle.

1. Smooth muscle. Pieces stripped from the intestinal wall may be stained for twenty-four hours with dilute hematoxylin. Tease in glycerin and alcohol, or, for permanent mounts, dehydrate and tease in oil.

2. Cross sections of the intestine will show smooth muscle in cross and in longitudinal sections.

3. Heart muscle. Teased specimens and very thin sections.

4. Voluntary muscle. Sections of a tongue will show fibers both in cross and in longitudinal section.

5. Injected muscle. Sections should be cut very thick to show capillaries. Such muscle carefully teased is very satisfactory.

6. Fresh voluntary fibers may be teased in alcohol and glycerin.

Nervous Tissue.

1. For bipolar cells study sections of the spinal ganglion.

2. For multipolar cells study sections of the cerebral cortex and spinal cord stained with Cox-Golgi method, as follows:

Potassium bichromate	20 parts.
Corrosive sublimate 5 per cent. sol	20 parts.
Distilled water	40 parts.
Potassium chromate, 5 per cent. sol	16 parts.

Specimens remain in this two weeks or two months; after which wash thoroughly twenty-four hours. Cut sections free-hand as thin as possible and place them in a saturated solution of lithium carbonate for twenty-four hours. Transfer to 95 per cent. alcohol, and then to clove oil, from which they are mounted in balsam on a glass slide and covered with a cover glass.

3. Fix a sciatic nerve with 0.5 per cent. osmic acid. Wash thoroughly in water and tease either in glycerin or dehydrate and tease in oil. Study structure of medullated fibers.

4. Make cross section of sciatic nerve.

Blood.

1. Dip a thin strip of filter paper in the blood of a frog and make a spread either on a cover glass or a glass slide. Dry in air and fix in 95 per cent. alcohol. Stain with hematoxylin and eosin. Wash in water and dry in air, after which the specimen may be mounted in balsam.

2. Study fresh specimens of human blood for rouleaux and crenated red blood corpuscles.

3. Thin blood spreads may be made:

(1) On glass slides by placing a drop of blood near

one end and with the end of a second slide spread it by making a single stroke toward the opposite end.

(2) Placing a small drop between two cover glasses and drawing them apart in such a way that their surfaces are always parallel.

(3) Saturate the end of some thin blotting paper and make a spread either on a cover glass or a glass slide.

4. Spreads are dried in air and then fixed, by heat (120° C.), for two hours, or equal parts of absolute alcohol and ether for two hours. They are then dried and stained. Wright's stain is a short method and fixes and stains a film at the same time.

(1) Stain a blood film with Wright's fluid one minute.

(2) Distilled water 2 min. Add in drops upon cover glass or slide.

(3) Wash in water until the film of blood becomes pink.

(4) Dry between filter paper and mount in balsam.

(For preparation of Wright's stain see "Pathological Technique," Mallory and Wright, Third Edition.)

5. Blood platelets are obtained by pricking the finger through a drop of 1 per cent. osmic acid.

6. Hemin crystals. Grind together on a slide equal parts of dry blood and salt. Add glacial acetic acid and cover with cover glass. Heat until gas bubbles escape. Examine with high-power of microscope.

Red Marrow.—With a pair of pinchers squeeze a drop from the end of a rib and spread on slide or

cover glass. Fix and stain as for blood. A spread may be made from the end of the femur or any of the long bones.

Blood-vessels.

1. Sections of the aorta.

2. Small arteries can be found in sections of the tongue or any other organ.

3. Sections of any large vein.

Lymphatics, Thymus Gland, Spleen.

1. Sections of lymphatic nodes.

2. Sections of thymus gland.

3. Sections of the spleen.

These tissues must be cut thin and not overstained.

Digestive System.

1. Teeth. Ground sections, technique as for bone.

2. Tongue. Section foliate papillæ of rabbit for taste buds.

3. Cross section of esophagus.

4. Sections of cardiac and pyloric end of stomach.

5. Small intestine. Injected specimen must be cut thick.

6. Sections of ileum for Peyer's patches.

7. Large intestine, including vermiform appendix.

Digestive Glands.

1. Sections of parotid and submaxillary gland.

2. Pancreas. Injected pancreas for areas of Langerhans.

3. Liver, including sections of injected organ cut thick.

Organs of Respiration.

1. Sections of thyroid gland.

2. Sections of trachea.

3. Lung, including thick sections of injected organ.

Urinary Organs.

1. Suprarenal bodies.

2. Kidneys. Sections of injected kidney and kidney pieces macerated with hydrochloric acid (see page 457).

3. Sections of ureters.

4. Bladder, preferably sections of one distended with fixing fluid.

Reproductive Organs.

1. Sections of testes with epididymis attached.

2. Vas deferens.

3. Sections of penis, preferably of baby or a fetus.

4. Prostate gland, preferably an old one.

5. Ovaries. Old enough to show corpora lutea.

6. Fallopian tubes. Sections of fundus and isthmus.

7. Uterus.

8. Placenta, preferably at half term.

9. Mammary gland.

The Skin and Appendages.

1. Sections of palm surface of finger.

2. Sections of the scalp, tangential and cross.

3. Nails. Sections of finger of fetus are very good.

Peripheral Nerve Endings and Spinal Cord.

1. Sections of duck's bill. Iron hematoxylin stain.

2. Pacinian corpuscles may be found in sections of the skin of the finger or in the connective tissue of sections of the pancreas. They may be teased out from the mesentery.

3. Spinal cord. The cord of the horse or ox is very satisfactory.

Brain.

1. Sections of cerebral cortex.
2. Sections of cerebellar cortex cut across the folds.
3. Sections of closed and open medulla.
4. Sections of the pons.

Sections of the medulla and pons should be cut thick and stained with Pal-Weigert method.

Celloidin method of imbedding is preferable.

The Eye.

1. Sections of the whole eye imbedded in celloidin.
2. Sections of the cornea.
3. Sections of the retina.
4. Sections of the eyelid.

The Internal Ear.

Sections of the cochlea must be decalcified.

Cochlea of a young kitten is very satisfactory.

STANDARD FIXING SOLUTIONS.

Carnoy's Acetic-alcohol Mixture.

Glacial acetic acid	1 part.
Absolute alcohol	3 parts.

Pieces one centimeter thick are fixed in one-half to one hour. The after-treatment is with absolute alcohol.

Osmic Acid.—One-half to one per cent. aqueous solution.

Fix for three to twenty-four hours and then wash thoroughly in running water.

Flemming's Solution.

Osmic acid, 1 per cent. aqueous solution	10 parts.
Chromic acid, 1 per cent. aqueous solution	25 parts.
Glacial acetic acid, 1 per cent. aqueous solution	10 parts.
Distilled water	55 parts.

Fix for twenty-four hours or more and wash thoroughly in running water.

Flemming's Strong Solution.

Osmic acid, 2 per cent. aqueous solution	4 parts.
Chromic acid, 1 per cent. aqueous solution	15 parts.
Glacial acetic acid	1 part.

This is a good fixing agent for nuclear structures and therefore for mitosis.

Corrosive Sublimate.

Saturated solution in distilled water. Fix for twenty-four hours or more and wash in running water. After twenty-four hours, transfer to 70 per cent. alcohol to which a few drops of iodin and potassium iodid have been added. The iodin removes any crystals of sublimate that may have formed.

Picric Acid.

Saturated aqueous solution. Fix for twenty-four hours, or longer, after which wash in 70 per cent. alcohol.

Picrosulphuric Acid.

Picric acid, saturated aqueous solution	100 parts.
Sulphuric acid, concentrated	1 part.
Distilled water	200 parts.

After-treatment same as for picric acid.

Nitric Acid.—Aqueous solution, 3 to 10 per cent.

Fix for several hours and wash thoroughly in running water.

Chromic Acid.—Aqueous solution $\frac{1}{3}$ to 1 per cent. Small pieces are fixed for twenty-four hours. Wash in running water and pass through the ascending grades of alcohol, preferably in the dark.

Müller's Fluid

Potassium bichromate	2.5 gm.
Sodium sulphate	1.0 gm.
Water	100 c.c.

Fix for several weeks, preferably in the dark. At first the fluid should be changed daily. Wash in running water for twenty-four hours and place directly in 70 per cent. alcohol. Dehydrate preferably in the dark.

Zenker's Fluid.

Potassium bichromate	2.5 gm.
Sodium sulphate	1.0 gm.
Corrosive sublimate	5.0 gm.
Glacial acetic acid	5.0 gm.
Water	100 gm.

It is better to add the acetic acid just before using and not to add it to the stock solution. Fix tissues in this fluid for six to twenty-four hours. Wash in running water twenty-four hours and transfer to alcohol, using the grades. Sublimate crystals are removed by iodized alcohol as with corrosive sublimate solutions.

Formalin.

Formalin (40 per cent. Formaldehyde)	5 to 10 parts.
Water	90 parts.

Small pieces are fixed in twelve to twenty-four hours. As sections do not stain well after this fixation, it

is better to transfer the pieces to some standard salt solution and then wash and dehydrate.

Potassium Bichromate and Formalin.

Potassium bichromate 2 per cent. aqueous solution	90 parts.
Formalin	10 parts.

Fix for several days or weeks. Wash in running water and dehydrate with alcohol. This is a good fixation for the central nervous system.

STANDARD STAINS.

Aqueous Borax-carmin Solution.

Borax	8 gm.
Carmin	2 gm.
Water	150 c.c.

Grind together the borax and carmin. Add the water and in twenty-four hours filter. Stain sections for twelve hours or longer. Treat with acid-alcohol as necessary.

Alcohol Borax-carmin Solution.

Carmin	3 gm.
Borax	4 gm.
Water	93 c.c.
Alcohol, 70 per cent	100 c.c.

Filter and stain as for the aqueous solution.

Cochineal Solution.

Cochineal, powdered	7 gm.
Alum, roasted	7 gm.
Water	100 c.c.

Boil down to one-half its volume, stirring freely. When cool filter and add a few drops of carbolic acid. This fluid does not overstain and acts rapidly. After staining wash in distilled water, as alcohol precipitates the alum.

Alum-carmin (Grenacher).

Alum solution, 3 per cent. to 5 per cent.	100 c.c.
Carmin	1 to 5 gm.

Boil for fifteen minutes, cool and filter. Add enough water to replace that lost by boiling. Wash the sections in water after staining.

Bohmer's Hematoxylin.

Hematoxylin	1 gm.
Alcohol, absolute	10 c.c.
Potassium alum	10 c.c.
Distilled water	200 c.c.

Dissolve the hematoxylin in alcohol and the alum in water. Add the first to the second solution while continually stirring. Allow this preparation to stand in an open jar for two weeks, to ripen, when the color will change from violet to blue. After filtering the stain is ready.

Delafield's Hematoxylin.

Hematoxylin crystals	4 gm.
Absolute alcohol	25 c.c.
Ammonium alum, sat. aq. sol.	400 c.c.
Alcohol 95 per cent.	100 c.c.
Glycerin	100 c.c.

Dissolve the hematoxylin in absolute alcohol and add the alum solution. Place in open vessel for four days, filter, and add the 95 per cent. alcohol and glycerin. In a few days filter again.

Ehrlich's Hematoxylin.

Hematoxylin crystals	2 gm.
Absolute alcohol	60 c.c.
Glycerin } saturated with	60 c.c.
Distilled water } ammonia-alum	60 c.c.
Glacial acetic acid	3 c.c.

Expose to light for a long time. It is ready for use when it acquires a deep red color.

Heidenhain's Iron Hematoxylin.

Sections that have been fixed in sublimate solutions are placed in a 2.5 per cent. aqueous solution of ammonium sulphate of iron for four to eight hours. Rinse thoroughly in water and place in a hematoxylin solution prepared as follows:

Hematoxylin crystals	1 gm.
Absolute alcohol	10 c.c.
Distilled water	90 c.c.

Dissolve the hematoxylin in the alcohol and add the water. This solution should stand in an open vessel for four weeks, and before using should be diluted with an equal volume of distilled water.

Stain the above sections twelve to twenty-four hours, rinse in tap water and return to ammonium sulphate of iron solution until black clouds cease to be given off from the sections. Rinse in distilled water, dehydrate, and mount in balsam.

This is a good stain for mitosis.

Anilin Stains.

These are basic or acid stains. The basic stains are safranin, methylene-blue, methyl green, gentian violet, methyl violet, Bismarck brown, thionin, and toluidin blue, and stain nuclei. The acid stains are eosin, erythrosin, acid fuchsin, orange G. and nigrosin, and stain cytoplasm.

These stains are used in water solutions and of $\frac{1}{2}$ to 1 per cent. strength, to which a little alcohol may be added.

Pal-Weigert Method of Staining Sections of Brain or Cord.

Mordant celloidin sections for twenty-four hours

in 3 to 5 per cent. aqueous solution of potassium bichromate. Wash in water and transfer to the following stain:

Hematoxylin crystals	1 gm.
Alcohol 95 per cent.	10 c.c.
Lithium carbonate, sat. aq. sol.	1 c.c.
Water	90 c.c.

Dissolve the hematoxylin in alcohol first, and then add the balance at the time of using. Stain the sections in this for twenty-four hours. Wash in water and transfer to a 0.25 per cent. fresh solution of potassium permanganate for one-half to two minutes. Wash freely in water and place in the following Pal solution:

Oxalic acid	1 gm.
Potassium sulphate	1 gm
Water	200 c.c.

This will differentiate the gray and white matter in one to three minutes. The nerve fibers should stain blue. If the sections are too dark they may be carried through the permanganate and Pal's solution a second time. Transfer to water for several hours, dehydrate, and mount in balsam.

For a more complete description of laboratory methods, including injections, fixing of tissues, and special staining methods, see the following texts:

"Pathological Technique," Mallory and Wright, Third Edition.

"Microtomist's Vademecum," Lee.

Böhm-Davidoff-Huber, "Histology," Second Edition, 1904.

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